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DIVISION OF BIOLOGICAL RESEARCH

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UNITED STATES DEPARTMENT OF THE INTERIOR
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FISH SPAWNING IN 1957 AND 1958

ELBERT H. AHLSTROM

The title on the program suggests that I should report on the spawning of various species of fish in 1957 and 1958, but I will have to confine my remarks mainly to sardines, because the identification and counts of eggs and larvae of other species from our plankton surveys has not been completed beyond the July 1957 cruise. However, the sardine material has been studied through April 1958 and shows striking changes under the warm conditions during the 1958 spawning season.

Before discussing this, we need to have the background of sardine spawning during previous years as it is known from the eggs taken in plankton nets during our systematic surveys. Figures 155 and 156 are charts giving yearly distribution of sardine eggs from 1951 to 1958. In our surveys the fish eggs and larvae are obtained in oblique plankton hauls made from a depth of approximately 140 meters to the surface. The net employed is 1-meter in diameter at the mouth by approximately 5 meters in length. It is constructed of No. 30 xxx silk grit gauze (mesh openings 0.55 mm.). The amount of water strained during each haul is recorded by a current meter, fastened in the mouth of the net. Based on the amount of water passing the current meter the number of eggs per haul was standardized to represent the numbers per 10 square meters of sea surface. Stations in the spawning area were occupied at approximately monthly intervals during the spawning season. The distribution charts (Figs. 155, 156, 157), which I will show you, were drawn from the sums of the standardized egg numbers taken at each station during each season. Sardine spawning that occurs in the Gulf of California is not taken into account in the charts; it has been investigated, however, particularly in 1956 and 1957.

Outside of the Gulf, sardine spawning in recent years has occurred mainly between Point Conception, California, and Point San Juanico, Baja California. For convenience I have divided the sardine spawning area into four subareas which are numbered in figure 157. Area two is Southern California, from Point Conception to San Diego. Area three is northern Baja California, extending down to about San Quentin Bay. Central Baja California has been divided into two areas: upper central Baja California, extending between Punta Baja and Point San Eugenio, and lower central Baja California, between Turtle Bay and San Juanico. Areas two and three together comprise the "northern spawning center," and the two central Baja California areas (areas four and five) the "southern spawning center." In comparing the series of years 1951 to 1958, shown in figures 155, 156, I would note that the most spectacular change that occurred during the last eight years did not take place in 1957 or 1958, but between 1953 and 1954. You will note from figure 155, that in 1952 and 1953 the center of spawning was in the southern spawning area off central Baja California. In fact, in 1952 only three percent of the sardine eggs were taken in the northern spawning center, and in 1953 only one percent. The percentage in the northern center in 1951 was six percent. The decline was progressive for these three years.

It is difficult to imagine a greater contrast between two seasons than occurred between 1953 and 1954. Sardine eggs were obtained in only 20 hauls in 1953 in the northern center; they were found in 149 hauls in 1954. In only two instances were sardine eggs taken at adjacent stations in 1953. In 1954 they spread continuously over most of the northern spawning area. We estimate that in 1953, 4 x 10^{12} eggs were spawned in the northern center, while 137 x 10^{12} eggs were spawned in 1954. Literally interpreting these figures, there was 35 times as much spawning in the northern center in 1954 as in 1953.

Furthermore, this difference in egg distribution was directly reflected in adult fish distribution as shown by the California commercial catch. In the 1952-53 and the 1953-54 seasons (the sardine fishing season, by law, began in November and continued through February 1st in these years), less than 5,000 tons of sardines were landed. When spawning became widespread in the northern spawning center in 1954, the catch immediately jumped to 67,000 tons. In years following 1954, spawning continued to be widespread in the northern center and the commercial catch also has continued fairly good.

As background for describing what happened in 1957, I should like to discuss the seasonal distribution of sardine spawning of the previous six years, which is illustrated in figure 157. In the northern spawning center (areas two and three in figure 157), eggs were taken mostly between February and July. Eighty percent occurred in May and June off Southern California and in April to June off northern Baja California. You will note that in the southern spawning center (areas four and five) the seasonal distribution is definitely bimodal. It builds up to a peak in March, then falls off to a minimum in June, and then there is again quite heavy spawning in July and August. This late-season spawning has no counterpart in the northern spawning center.

Also, the late-season spawning occurs at quite different temperatures than the early spawning. The earlier spawning during recent years has occurred at temperatures of about 15.5°C on the average, while the late-season spawning has been at an average temperature of somewhat over 18°C, or about 2.5° difference in temperature. These are the temperatures measured at the 10-meter level. Sardine eggs are confined to the upper mixed layer and usually are most abundant in the upper 20 meters of this layer. The 10-meter temperature is usually a good indicator of the temperature of the whole upper mixed layer.

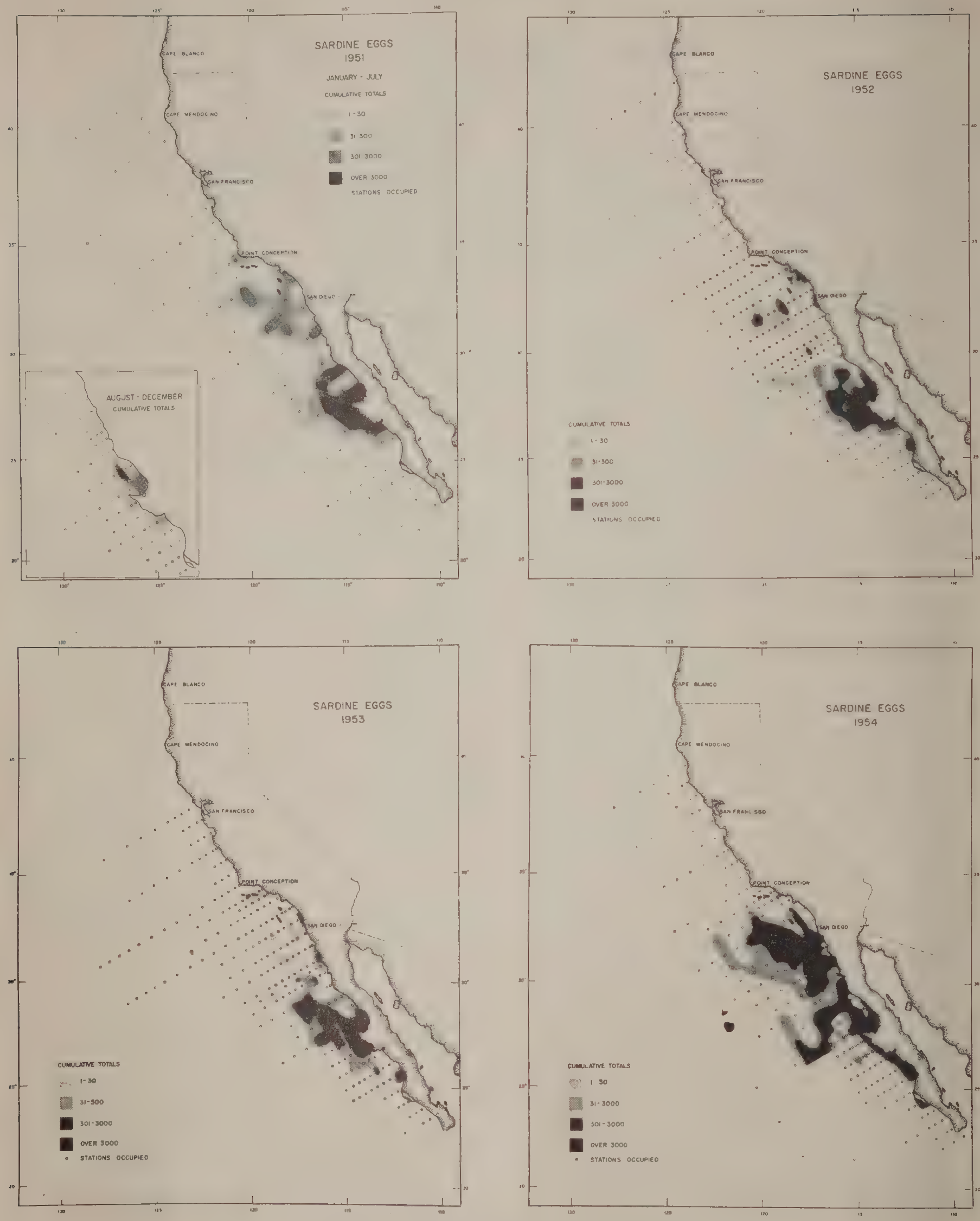

SARDINE EGGS
1951
JANUARY - JULY
CUMULATIVE TOTALS
1-30
31-300
301-3000
OVER 3000
STATIONS OCCUPIED
AUGUST - DECEMBER
CUMULATIVE TOTALS
CAPE BLANCO
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
SARDINE EGGS
1952
CUMULATIVE TOTALS
1-30
31-300
301-3000
OVER 3000
STATIONS OCCUPIED
SARDINE EGGS
1953
CUMULATIVE TOTALS
1-30
31-300
301-3000
OVER 3000
STATIONS OCCUPIED
SARDINE EGGS
1954
CUMULATIVE TOTALS
1-30
31-3000
301-3000
OVER 3000
STATIONS OCCUPIED
130
125
120
115
110
40
35
30
25
20

FIGURE 155. Distribution and abundance of sardine eggs.

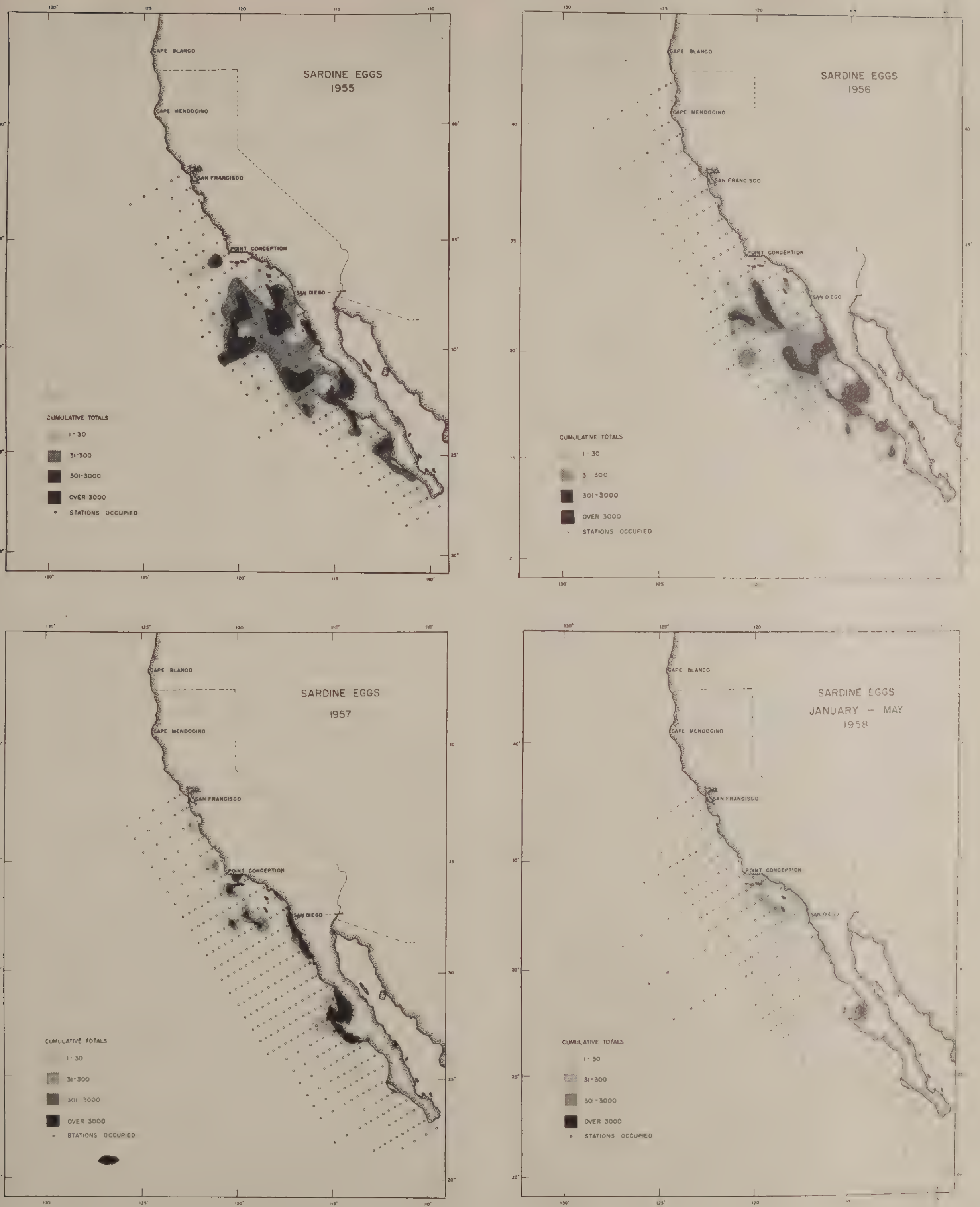

SARDINE EGGS
1955
CAPE BLANCO
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
CUMULATIVE TOTALS
1-30
31-300
301-3000
OVER 3000
STATIONS OCCUPIED
SARDINE EGGS
1956
SARDINE EGGS
1957
SARDINE EGGS
JANUARY – MAY
1958
130°
125°
120°
115°
110°
40°
35°
30°
25°
20°

FIGURE 156. Distribution and abundance of sardine eggs.

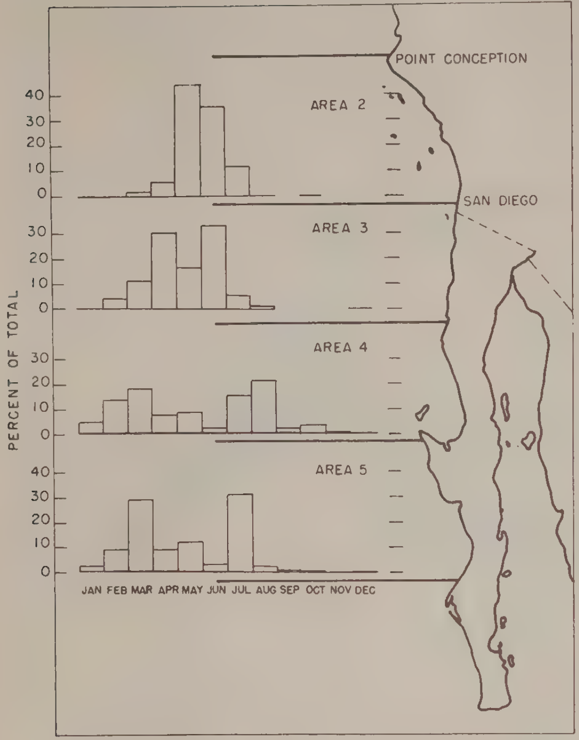


FIGURE 157. Seasonal distribution of sardine spawning, as indicated by the monthly mean number of eggs for the six-year period 1951 to 1956, by major areas.

It might be pertinent to give some information on the temperature at which sardine spawning has occurred in the different areas. In the Southern California area during the six-year period 1951 through 1956, the average temperature at all stations yielding sardine eggs was 14.7°C. There was then a gradual progression in temperature going southward. In the northern Baja California area the average was 15.1°, or 0.4° higher; in the upper central Baja California area it was 15.4°, and in the lower central Baja California area it was 15.7°.

In 1957, spawning in the Southern California area which occurred from March to July, was at an average temperature of 14.9°. This is quite close to the average of the preceding six years. Off northern Baja California, the 1957 temperature was 15.4°, as compared with the average of 15.1° during the preceding six-year period. In the upper central Baja California area the temperature was 16.4°. This was a degree higher than the average of the preceding six years. In the southernmost area it was 16.2° at the only two stations where eggs were taken.

These temperatures I have given were the averages for January through June, that is, the earlier months of the season. The fall spawning temperature had a still more marked difference. For fall, the six-year average was 18.1° (areas four and five combined). Last year it was 21.2°. During the latter part of 1957 we know that temperatures increased all along the coast. The increase occurred after July, mostly. Spawning in the northern center was over by July, so it was not much influenced by the change in temperature.

By 1957 spawning was light compared to some of the preceding years. The most striking thing is that there were practically no spring spawners off central Baja California in 1957. In this area the spring spawning was only about 2 percent as large as the fall spawning in 1957. In preceding years, the spring spawning had been (with one exception) considerably larger than the fall spawning. We are pretty much convinced that the early spawners of central Baja California are the same group of fish that spawn off Southern California and northern Baja California. The fall spawning group may be a distinct subpopulation or race. I think the evidence of 1957, when we had practically no spawning in the southern center during the first six months and heavy spawning during the last six, is good support for considering this group to be a separate subpopulation. As I said earlier, the fall spawning was at a higher temperature than usual, the average being over 21°.

The distribution during the first four months in 1958 was very unusual. As we have seen in the average seasonal distribution chart of figure 157, practically no eggs are taken off Southern California in January or February and a small amount in March. April has only about five percent of the seasonal total. In 1958, however, fairly heavy spawning started in February and spawning in March had the distribution shown in the chart. Spawning centered in the area of the Santa Barbara Channel Islands, with a strip along the coast of Southern California and another zone offshore from Santa Catalina and San Clemente Islands. The only other center of heavy spawning was in Sebastian Viscaino Bay. Spawning did not occur offshore in the southern center, which is the usual distribution in this center during the spring months. Also, there was hardly any spawning between Sebastian Viscaino Bay and Southern California.

Spawning temperatures off Southern California in 1958 during January through May have averaged 15.1°C. This is only about 0.4° higher than the six-year average. The 1958 season has paralleled the 1941 season off Southern California in time of spawning, but not in temperature of spawning. As you will recall from a number of discussions, 1941 was an unusually warm year; the average temperature of spawning off Southern California was 16.1°C. This is not only a full degree higher than the spawning temperatures off Southern California during January-May 1958, but a higher value than that found for any of the four areas during the regular spawning period in 1951-1956. This points up the fact that one area like Southern California, over a period of time, will have a wider average temperature range than is ordinarily found throughout the spawning range of the sardine.

DISCUSSION

Berner: Is the implication here that early spawning sardines off Southern California might be the first hump in the seasonal graphs of the southern center and these fish have migrated north?

Ahlstrom: Yes.

Fleming: May I ask another: Do they spawn only once a year?

Ahlstrom: This is the kind of information that we would like to have but which is very difficult to get. When you examine the frequency distribution of diameters of ova in the gonads of maturing female sardines, you find that there are several modes. From this kind of evidence it is usually thought that three batches of eggs are destined to be spawned during the year. Whether all three actually are spawned or not is the controversial point.

Wooster: You may be going to get to this, but as I understand it, one of the uses you make of these data is to estimate the size of the spawning stock. To do this you eventually integrate these charts and multiply them by some factor which gives you the number of adult sardines. If this is true, then there was an extremely great decrease in the size of the population of sardines from 1956 to 1957, if I am integrating properly. Is this the conclusion you have drawn?

Ahlstrom: Yes. In estimating the number of spawners we have assumed that a female spawns on the average about 100,000 eggs. Allowing this figure and a 50-50 sex ratio, we estimate that the spawning population in 1956 numbered approximately five billion fish, while in 1957 it was reduced to about two billion fish.

Isaacs: What is the population drop over a period of seven years?

Ahlstrom: From twelve to two billion fish.

Wooster: To continue, in these first six charts your average population in each year is more or less the same size population.

Ahlstrom: No. The distribution charts are simple sums of eggs taken at each station through the season. For estimating the total number of eggs spawned the numbers of eggs are integrated over time and space. The total spawning population is estimated from these integrated egg numbers. There was a very big drop in spawning population between 1951 and 1952. The numbers, including both the northern and southern populations, dropped from twelve billion down to below three billion. The 1953 and 1954 values are around eight billion.

We think these variations in adult population are caused by variations in year-class strength. From the age-composition and quantity of the California sardine catch we have a very good estimate of the relative year-class strength. There was a series of three big year classes in 1946, 1947, and 1948. In 1949 and 1950 the survival to commercial size was one one-hundredths as good as in 1947. For example, the 1947 year class, produced from a relatively small population, amounted to over 3000 million fish as measured by the subsequent catch. In 1952 we were feeling the influence of the weak 1949 year-class as three-year-olds, and the weak 1950 year-class as two-year-olds. Since 1948 the only moderately good year class we have had in the fishery was the 1952 year-class. The 1951 class was somewhat better than 1949 and 1950, but not as good the 1952. In the spawning population of 1954, especially, we have this influence of the 1952 year-class, and there has been a gradual decrease in population since then, because succeeding year classes have not been very good. But as John Radovich probably mentioned yesterday, present indications are that from this small spawning population in 1957, there has been fairly good survival.

Radovich: Right now the picture is extremely confused because the samples we are getting in the 1958 bait catches contain fish about the size they should be if they were of the 1957 year-class, except they seem to have an extra ring in their scales.

Isaacs: What happened to all these fish? Two-thirds of them disappeared between 1956 and 1957. Is this explained on the year-class strength chart?

Radovich: The 1952 year-class actually supplied more than 50 percent of the catch for a period of about three years and tapered off without another year-class coming in.

Murphy: What is the typical number of year-classes in a spawning population?

Radovich: I would say, predominantly three. Only about half of the fish are spawning at the age of two.

Question: Why do you take the 10-meter temperature when it comes to spawning?

Ahlstrom: We have done a number of studies on vertical distribution of sardine eggs, and have found that the distribution varies in different places and at different times. There are several things that are constant in the vertical distribution, however. The eggs are always in the upper mixed layer above the thermocline, and where the thermocline is shallow, the vertical distribution is shallow. When there is a deep mixed layer as is true at some offshore stations, the eggs may be distributed quite deeply. But in most cases where this happens, the temperature is rather uniform throughout the mixed layer so that the 10-meter temperature is a very good representative temperature of that layer. In a situation where you have a gradual change in temperature from the surface downward, there is no single temperature that would be fully representative.

Arthur: Would you not expect to find the eggs at their density layer? I am thinking of the waters with more shallow thermocline along the coast.

Ahlstrom: In one set of the vertical distribution data we had an interesting difference in spawning. In a sample there are usually the eggs of the three previous days of spawning, and these can be distinguished by the stage of the embryo. At this station, one-day-old eggs and the three-day-old eggs had their center of distribution at about the 40-meters depth. The two-day-old eggs had their highest concentration near the surface and declined quite rapidly downward. The same distribution was found in both day and night series. So to me, at least, this suggests that sometimes the sardines may be spawning as deep as 40 meters, and at other times spawning near the surface in the same water mass. The temperature was uniform throughout the egg-bearing stratum so that temperature did not affect the distribution.

Fleming: Can you tell us something about the frequency of the cruises here, and whether you have any time series at stations?

Ahlstrom: The cruises are roughly a month apart. The coverage has been the most intensive during the first seven months of the year, and somewhat less intensive during the later five months, so that the fall spawning has been undersampled.

Fleming: Have you ever stayed in an area for a month to see what happens?

Ahlstrom: We have stayed in an area on several occasions for a period of three to five days.

Fleming: Does this spawning seem to go on fairly regularly day after day? What I am wondering is how valid is the sampling? Could you miss a whole spawning population when you only sample once a month?

Ahlstrom: Although each station is sampled only once a month, the samples contain two or three days' eggs so that time coverage amounts to about one-tenth of the period between cruises.

Fleming: I shudder to think how little you are actually comparing.

Ahlstrom: I will point out one thing. When there is spawning of any intensity in an area, there are usually several days' eggs present. Take 1941 that you mentioned earlier. The first cruise of that year covered 41 stations off Southern California. We found eggs in every haul taken in this area, and in every haul there were all of the previous days' eggs that could have been expected from continuous daily spawning. This suggests that the spawning was continuous rather than intermittent during the month.

Johnson: Wouldn't the presence of larvae indicate whether or not you had missed spawning?

Ahlstrom: Yes, this is a nice thing about larvae; they are more conservative in time than the eggs. A sample of larvae represents the accumulation over approximately a month and a half.

Fleming: So your larvae do reassure you.

Klein: Does the spawning in Viscaino Bay follow the general pattern, or does it remain fairly constant?

Ahlstrom: Fall spawning was very heavy in 1953. In most seasons it was less than 20 to 25 percent of the total spawning.

Hubbs: Do you get any periodicity in frequency of spawning?

Ahlstrom: We have looked for this a number of times but we have not been able to see anything in our data suggesting this.

Radovich: Since sardines in Sebastian Viscaino Bay spawn in warmer waters and at a different time-space interval than the rest of the sardine population, they may be a genetically different population. Do you have any indication of fall spawning off Southern California during the time the Sebastian Viscaino Bay fish are spawning?

Ahlstrom: The 1957 material examined thus far does not show this. When we have completely worked up the 1957 collections we might find this.

Radovich: I am trying to identify these small fish that seem to be older than they should be. They may represent that southern group, which are smaller for their age than the others.

Question: What species, other than sardines, do you get in your hauls?

Ahlstrom: Eleven or twelve species dominate the material making up about 80 percent of all the larvae we take. In recent years the most abundant has been the anchovy. Also of considerable importance are jack mackerel and hake. The latter is a commercial species in some parts of the world but is not caught commercially in our area. Next to anchovy, hake larvae have always been the most abundant. In last year's collections a notable thing was the large number of the larger sizes of jack mackerel larvae. It seems that the apparent survival of the jack mackerel year-class was surprisingly good. This will have to be determined later by the fishery.

Radovich: Numerous young jack mackerel were caught in Morro Bay in 1957.

Ahlstrom: This probably is an indication that it is a successful year-class. Certainly the larval collections suggest that it should be the best year-class of jack mackerel since we began our surveys.

I might mention one other thing about the apparent relation between success in sardine spawning and temperature. It has been known for a number of years that there often is good survival in years that are warmer than usual. Mr. Sette made a preliminary study of this some years ago, I believe. It showed very well the success of the 1926 class and 1931 class during these two warm years. 1941, another warm year, was somewhat of an exception to this; it was not a bad year-class but it was not spectacular. Again, the 1957 class is a good one in a warmer than usual year. The 1939 year-class was an outstanding class that was produced during a partly very cold, and partly very warm year. The 1932 class was also very successful, although the temperature in 1932 was somewhat below normal. It is interesting to note that the years 1932, 1939 and 1957 have one thing in common. During the last half of each of these years the winds died down. This, at least, was a condition that would favor a shoreward transport of larvae and also it might have been conducive to the heating up of the water.

Murphy: Do you ever have any very striking indications of mortality among the eggs and larvae?

Ahlstrom: We almost always find abnormal looking eggs in our hauls, but as far as these might relate to unusual mortality we have found nothing noteworthy.

Hubbs: Didn't Carl Oppenheimer find tremendous numbers of diseased eggs?

Ahlstrom: There is a problem in collecting viable eggs. Among the early stage eggs there is a large proportion of abnormal appearing eggs in our plankton hauls. This does not apply to sardines alone, but to eggs in general. In fact, this condition makes identification of fish eggs difficult because they become milky and so opaque that the embryonic features cannot be seen. Some of the later stages of eggs are in the same condition, but it is not nearly as prevalent after the embryo has encircled the yolk at the anal pore closure. I suggest that this condition may be due to rupture of the embryonic membrane and that it may be caused by mechanical injury during the collection of the eggs.

Sette: I would like to remark that this condition is quite general in fish eggs of various species in both the Atlantic and Pacific.

Hubbs: Carl Oppenheimer showed me some preparations of eggs he had recently collected locally. The milky area was swimming with bacteria. Although a little time elapsed while getting them under the microscope, there seemed to be much too much bacterial increase in a short time to be due to infection after collecting.

Ahlstrom: We have had difficulty with Carl's results. We have collected a number of fish eggs recently, sardines and other species, and have incubated them at constant temperatures. We have had good survival. We take out normal looking eggs and it is very unusual to have these die. Carl experienced a very high mortality, but ours is much better.

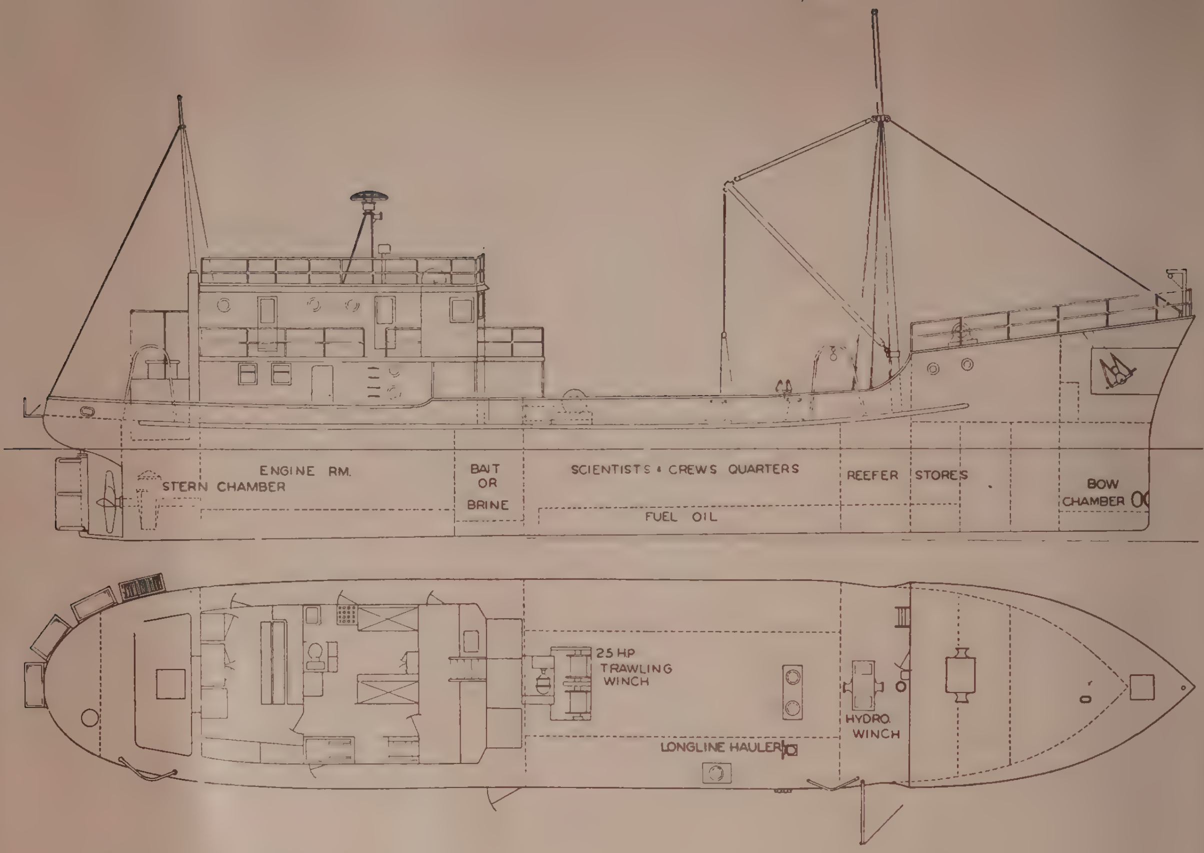
Hubbs: Have you picked out some milky looking eggs? This would be very interesting.

Sette: Are not the milky eggs dead when first seen?

Ahlstrom: All the live ones are translucent—transparent. You can hardly see them unless you get the light reflecting the right way.

NOTE: The editors offer their opinion that Hubbs and Ahlstrom were discussing two different phenomena. The former related Oppenheimer's findings on the nature of the "milky" eggs, i.e., whether or not they were diseased; the latter was relating his experience as to the viability of eggs other than the milky ones, i.e., normal healthy eggs.

THE CHARLES H. GILBERT



Research Vessel is Fitted For Underwater Observation of Fish

By
Albert K. Akana Jr.
Herbert J. Mann
Robert E. K. D. Lee

● *Charles H. Gilbert,* U. S. Bureau of Commercial Fisheries research vessel attached to the Honolulu Biological Laboratory (HBL), has recently undergone extensive alterations which make her one of the most modern and versatile vessels of her class. The modifications to the vessel, including startling innovations such as an underwater bow chamber for observing fish and a bulbous bow, were accomplished at Gunderson Bros. Engineering Corp. of Portland, Ore., under the direction of L. C. Norgaard and Associates of San Francisco.

Built in April, 1952, by the Tacoma Boatbuilding Co., Inc., Tacoma, Wash. the *Gilbert* has now had two major alterations. The vessel's over-all length was 84′2″ until January, 1954, when a 28′ parallel hull section was added at Colberg Boat Works of Stockton, Calif., increasing over-all length to 112′2″.

In June, 1959, an underwater viewing chamber was installed at the port quarter, forward of the propeller and directly beneath the fishing racks. This installation, made at the shipyard of the Hawaiian Dredging and Construction Co., Honolulu, followed extensive investigations by HBL staff members of various means for accomplishing underwater observations, including overside ladders and caissons. Excessive turbulence, which hindered the observer's vision, and the cumbersome handling of the equipment were the principal drawbacks of these early installations. The chamber, comfortably accommodating one person, has two glass ports for direct observation of tuna behavior during fishing operations.

NOTE—Authors are members of the staff of the Honolulu Biological Laboratory, U. S. Bureau of Commercial Fisheries, Honolulu, Hawaii. Mr. Akana is marine superintendent; Mr. Mann is fishery methods and equipment specialist; and Mr. Lee is port captain. This article is published by Pacific Fisherman with the permission of the Director, U. S. Bureau of Commercial Fisheries.

Advanced Features of the "New" Gilbert

Several outstanding and advanced features were incorporated in the "new" *Gilbert* during the second major alteration at the shipyard of the Gunderson Bros. during the period November 24, 1959, to March 17, 1960.

As a result of the success of the stern underwater viewing chamber, and to meet the increasing needs of marine biologists in the study of fish behavior, an underwater observation chamber was installed in the vessel's new bow. The original bow was cut away and a new "streamlined" bulbous bow was added. The "bulb" comfortably accommodates a single observer who is able to take notes, movies or photographs of fish action through three 1"x12"x18" oval tempered glass ports which are installed forward, port and starboard 6' below the waterline. Access to the chamber is from a watertight hatch forward of a watertight bulkhead designed to prevent flooding in case of an accident. It is noteworthy that the *Gilbert* is perhaps the first fishery research vessel to be fitted with a bulbous bow and fore and aft underwater observation chambers. It is anticipated that this new approach to research will bring about better knowledge of tuna behavior which may improve or introduce new fishing methods and techniques to increase the efficiency of capturing tuna.

Observation blister on the **Charles H. Gilbert's** hull, permit [illegible] er observation of tuna behavior while they are being fished [illegible] ks immediately above.

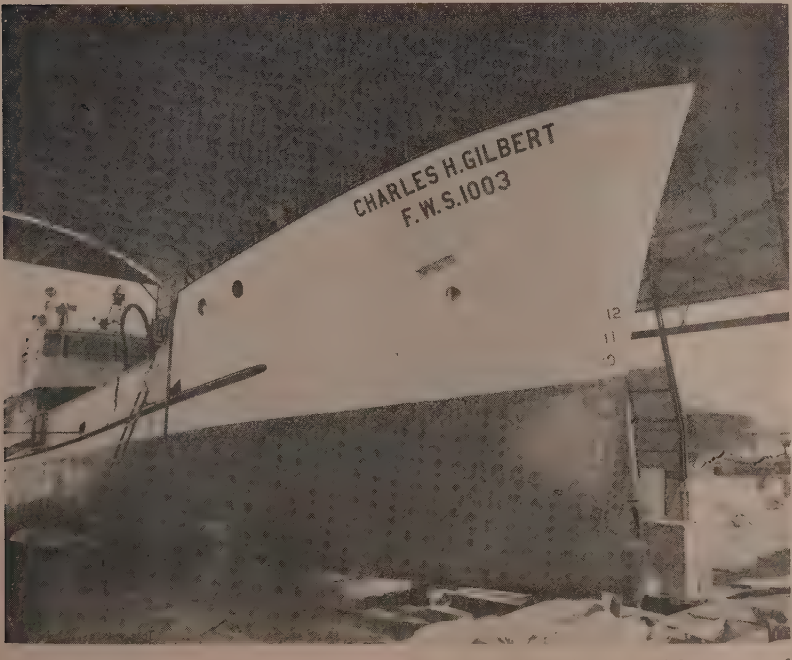
Other alterations include new, air-conditioned; midship quarters; new pilot house with a steering console using Sperry hydraulic system and a new propulsion engine. The vessel is now repowered with a new Caterpillar D397 (Series D) turbocharged marine diesel engine which developed 500 hp. at 1200 rpm. during trials. The new engine is fitted with hydraulically operated [illegible] se and reduction gears [illegible] Coolidge 74½" diar [illegible] tch 3-bladed, bronze p [illegible] starting is accomplish [illegible] can Bosch starting [illegible] test made over a me [illegible] 10 knots was maintaine [illegible] rpm with the vessel in [illegible] ade condition.

The ship's hold, forn [illegible] area for gear and equi [illegible] vided into three statero [illegible] s for use by scientific [illegible] nel, each containing two built- [illegible] k, chair and lavatory ar [illegible] ar- ters with six berths [illegible] ory. Below deck covering [illegible] tile.

To equip the vess [illegible] ions in tropical waters, ar [illegible] ning unit has been install [illegible] the hold quarters. This [illegible] Delco OU-30A with output [illegible] f 30,-500 BTR/HR. The [illegible] is led by ducts to adjustabl [illegible] in each of the rooms.

In addition to berth accommoda- tions in the hold, ther [illegible] re four bertl [illegible] in the main deck qu [illegible] s and two i [illegible] the captain's statero [illegible] on the brid [illegible] deck. This stateroom [illegible] equipped w [illegible] a desk, chair and lav [illegible] ry.

The bridge deck h [illegible] e was enlar [illegible] aft to provide a roo [illegible] which serv [illegible] a library, conferenc [illegible] room and [illegible] laboratory. The wh [illegible] ouse wa [illegible] tended forward to [illegible] comm [illegible] control console which is equipped with a Sperry magnetic compass pilot,



Bulbous bow and forward observation ports provided by modifications of the hull of the research vessel Charles H. Gilbert.

Sperry hydraulic steering and Westinghouse controls for the main engine. The flying bridge is also equipped with a control console of similar arrangement. Steering is accomplished by levers.

Other Distinguishing Features

● The vessel is equipped with Sperry rudder indicators, loran and rdf. RCA radar, three transmitters and receiver sets, two fathometers, one of which is capable of recording depth to 6,000 fathoms, a double drum winch for midwater trawling, a longline hauler, a 15-hp. plankton and hydrographic winch, a 7.5-hp. hydraulic powered BT winch and a bait tank aft which was converted into a portable unit.

After completion of the alteration work at the shipyard, the *Gilbert* departed Portland, Ore., on March 18 on a shakedown cruise to San Pedro. Following adjustments to gear and equipment in San Pedro, the vessel departed for a 2-month cruise along the west coast of Mexico and Central America with a complement of 11 crewmen and 4 scientific personnel. She returned to Honolulu, her homeport, on May 23, 1960.

All modifications have proved to be outstandingly successful; those that improve her qualities as a research tool, those that improve vessel operation and those that improve living accommodations. As she now exists, the *Gilbert* is the most modern, versatile research vessel of her class. No additional major modifications are planned.

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The Vertical Migration of *Mysis relicta* in Lakes Huron and Michigan[1,2]

#3

By Alfred M. Beeton

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ABSTRACT

During the day *Mysis relicta* could be taken only near the bottom of Lakes Huron and Michigan. In the evening they migrated into the overlying strata as the surface light intensity decreased from 15 to 1 foot-candles. Frequently the mysids migrated through the metalimnion when first ascending, but later in the night the majority occurred in or immediately below this layer. As the length of day decreased following the summer solstice, the mysids ascended progressively earlier each evening and descended later each morning (they descended when the surface light intensity was increasing from 10^{3} to 10^{2} foot-candle). Moonlight and fog influenced the extent and time of vertical migration.

The optimum light intensity for mysids is so low that they are concentrated near the bottom during the day. As the light decreases at sunset, they move upward rapidly; possibly because of a positive reaction to decreasing light. Their night-time distribution is determined by their response to the existing light and thermal conditions. Their dawn descent may be due to a photo-negative condition which originated during the night.

INTRODUCTION

Limited data on diurnal changes in the vertical distribution of the opossum shrimp, *Mysis relicta* Lovén, have been interpreted as active vertical migrations by several investigators (Dakin and Latarche, 1913; Juday and Birge, 1927; Valle, 1930; Southern and Gardiner, 1932; Langford, 1938; Larkin, 1948). Recently, however, Holmquist (1959, p. 180) has stated:

> The supposed diurnal migrations, which were often referred to in the literature, are apparently not regular migrations . . . . The observations of pelagic specimens in surface water during the night may be ascribed merely to the fact that some few specimens of the population go astray during the dark hours when the absence of light widens the tolerable world around them.

Holmquist's skepticism is justified in part, since most comments on vertical migrations of *M. relicta* are based on scanty observations to the effect that they can be captured near the surface at night and not during the day (Dakin and Latarche, 1913; Juday and Birge, 1927; Larkin, 1948). More comprehensive studies of their vertical movements have been inconclusive since only a relatively few mysids were captured (Southern and Gardner, 1932; Langford, 1938). Vertical migrations of marine mysids are, however, well documented (Russell, 1927, Fage, 1933; MacKintosh, 1934; Tattersall and Tattersall, 1951; Hulburt,

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[1] Received for publication, February 23, 1960.

[2] Based on a thesis submitted in partial fulfilment of the requirements for Ph.D. degree, University of Michigan, 1958.

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Printed in Canada.

1957). It seems reasonable that freshwater mysids should demonstrate similar behaviour.

This study had three objectives: (1) to ascertain whether the ascent of *M. relicta* into the upper water strata at night is a true vertical migration; (2) to determine which environmental factors may govern this behaviour; (3) to deduce possible ways in which these factors exert their influence.

Knowledge of the vertical migration of mysids as well as other crustaceans that live on or near the bottom in the deeper waters of the Great Lakes is of consequence, since the numerous studies of food habits of Great Lakes fishes have shown they are important fish-food organisms, significant in the trophic cycle of the lakes. The importance of these vertical migrations to the trophic dynamics of freshwater as well as marine environments has received little consideration. Frequently it has been stated that in areas where there is little or no vertical mixing of the water, biological-productivity cycles must occur *in situ*. Furthermore, it has been suggested that bottom organisms must rely upon peaks in epilimnial productivity cycles that precipitate organic matter to the bottom (Beklemishev, 1957). Neither of these concepts gives sufficient consideration to the extensive migrations of plankters and certain bottom organisms from the hypolimnion into the epilimnion. Most of these animals feed on detritus that has settled from the overlying water, but many can feed on plankton by migrating into upper strata. Consequently, their daily vertical movements afford a means whereby nutrients are transported to other trophic levels during periods of limited vertical mixing.

The review of the manuscript and valuable suggestions made by Drs David C. Chandler, Ralph Hile, and Stanford H. Smith are gratefully acknowledged.

METHODS

Field work was conducted aboard the research vessel *Cisco* of the Great Lakes Biological Laboratory, Bureau of Commercial Fisheries. Ten vertical-migration studies were conducted in Lake Michigan -7 series of samples were taken at Station 13 about 8 miles west of Grand Haven, Michigan (43°03′00″ N; 86°24′10″ W), June through November 1954, and 3 at Station 76e approximately 3 miles southwest of Frankfort, Michigan (44°34′00″ N; 86°18′40″ W), June, August, and October 1955. One study was made in Lake Huron at Station 69 about 26 miles northeast of Harbor Beach, Michigan (43°58′30″ N; 82°08′40″ W), in August 1956.

Three plankton-sampling devices were used: Clarke–Bumpus samplers, No. 2- and No. 10-mesh silk nets; $\frac{1}{4}$-metre nets, No. 32 grit cloth[3]; and $\frac{1}{2}$-metre nets, No. 2 mesh and No. 32 grit cloth. Horizontal tows were made with the Clarke–Bumpus samplers. These samplers were calibrated by towing them a known distance. The $\frac{1}{4}$-metre nets were attached to trawls either at the middle of the float lines, approximately 1.8 m off the bottom when the trawl was in operation, or on the rope connecting the float and lead lines approximately 0.6 m off the bottom. Data from the nets attached to trawls served only to indicate the occurrence of *Mysis*. Nonclosing ½-metre nets were used for a few collections in 1954. A special ½-metre closing net, made of 32 grit cloth and canvas, was used in 1955 and 1956. The grit-cloth section tapered from a diameter of 50 cm to 6 cm, within a length of 175 cm. The canvas formed the cylindrical front of the net, 50-cm diameter, 60-cm length. The tripping mechanism for opening and closing this net was devised by Leavitt (1935). Welsh, Chace, and Nunnemacher (1937), and Leavitt (1938) modified this mechanism and described its use in considerable detail. Tows made with ½-metre nets were horizontal. The volume of flow through the closing ½-metre net was calculated from data on the ship's speed and exact time between opening and closing the net. Records for tows made with nonclosing ½-metre nets were not treated as part of the quantitative data. A bronze depressor plate exerting a vertical pull of approximately 700 lb (320 kg), kept the nets at a constant depth. Tow depth was determined by the relationship between the length of cable below the surface and the angle between the surface and cable. Additional information on field operations is given by Wells (in press).

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[3] The number of meshes in these straining fabrics is as follows: No. 2 silk, 54 meshes/inch or 21/cm; No. 10 silk, 109 meshes/inch or 43/cm; No. 32 grit cloth, 37 meshes/inch or 14.5/cm.

Quantitative data on the vertical distribution of *M. relicta* are presented as number of mysids per 5,000 litres, to facilitate the use of information from both the ½-metre net and the Clarke-Bumpus samplers. The stated number of mysids present at a given depth is recognized as an approximation, but one with considerable quantitative value. All quantitative data for 1954 are from Clarke-Bumpus samplers. Information on the number of mysids taken per tow with nonclosing ½-metre nets, although not quantitative, provides additional data on the times of ascent and descent (Table I). Quantitative results of sampling with the Clarke–Bumpus samplers and closing ½-metre nets in 1955 and 1956 are combined in Tables II and III; agreement between data obtained with the Clarke-Bumpus samplers and the closing ½-metre net was reasonably good. The Clarke Bumpus samplers probably gave more accurate estimates than did the ½-metre net because of the flow metres on the samplers. The assumption that flow through the ½-metre ring was not reduced by the grit cloth net is of questionable accuracy since the extent to which this net would reduce the flow is unknown.

Continuous records of surface temperatures were obtained from a resistance thermometer. Reversing thermometers attached to Nansen bottles, and bathythermographs, were used for subsurface temperatures.

Light-penetration measurements were made with a pair of Model 856YR Photronic photoelectric cells, matched for output and linearity, and a Model 622 Weston microammeter. Light intensity at the surface was measured with one photoelectric cell and subsurface intensity with the other. Nine pairs of matched Corning-glass colour filters were used with the photoelectric cells to determine the spectral transmission of Great Lakes waters. The glass colour filters employed were No. 2404, 2418, 3482, 3384, 3387, 3389, 3850, 7380 and 5970; the spectral transmission of these filters is given by Corning Glass Works (1948).

Light-intensity measurements were not made in 1954 and 1955. Consequently, values for surface light intensity were calculated from graphs published by Brown

TABLE I. Vertical distribution of *Mysis relicta* at Station 13 (depth, 74 metres) in Lake Michigan, 1954. Number of sexually differentiated (D) and sexually undifferentiated (U) mysids per 5,000 litres. Clock times indicate the start (at surface) and end (deepest sample) of a series of tows approximately 10 minutes apart.

Date and time (EST)	Type of sampler[a]	Depth (*metres*)									
		Surface		10		20		30		40	
		D	U	D	U	D	U	D	U	D	U
June 6											
14:00–14:20	C–B	0.0	0.0	0.0	0.0	. . .	. . .	. . .	. . .	. . .	. . .
16:00–16:20	C–B	0.0	0.0	0.0	0.0	. . .	. . .	. . .	. . .	. . .	. . .
18:00–18:20	C–B	0.0	0.0	0.0	0.0	. . .	. . .	. . .	. . .	. . .	. . .
20:40–21:00	C–B	0.0	0.0	0.0	0.0	. . .	. . .	. . .	. . .	. . .	. . .
22:00–22:20	C–B	0.4	0.4	3.2	38.1	. . .	. . .	. . .	. . .	. . .	. . .
24:00–00:20	C–B	0.0	1.8	1.0	21.8	. . .	. . .	. . .	. . .	. . .	. . .
01:00–01:10	C–B	0.0	6.7	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
June 27–28											
22:00–22:30	C–B	0.0	0.0[b]	22.3	102.8	8.5	46.3[c]	. . .	. . .	. . .	. . .
24:00–00:50	C–B	0.0	0.0	12.3	100.7	4.2	24.0	0.7	20.5	0.7	6.6[d]
02:00–02:40	C–B	0.0	0.0	0.0	0.0	6.5	31.2	. . .	. . .	0.0	0.0[e]
03:30–03:40	M	. . .	. . .	. . .	15[f]	. . .	. . .	. . .	. . .	. . .	. . .
04:00–04:50	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
July 16–17											
19:00–19:50	C–B	0.0	0.0	0.0	0.0[e]	0.0	0.0	0.0	0.0	0.0	0.0
21:00–21:50	C–B	0.0	0.0	0.0	9.6	2.1	52.9	0.8	5.2	0.7	3.2
23:00–23:50	C–B	0.0	0.0	0.0	0.0	2.0	86.1	3.9	13.7	1.5	1.5
01:00–01:50	C–B	0.0	0.0	0.0	0.0	0.4	11.4	8.6	32.6	5.1	3.5
03:00–03:50	C–B	0.0	0.0	0.0	0.0	0.0	4.6	11.1	38.5	7.8	6.1
04:30–05:20	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
August 7											
17:30–18:20	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19:45–20:35	C–B	0.0	0.0	0.0	0.0	0.0	0.0	5.6	7.2	0.0	4.4
21:30–22:20	C–B	0.0	0.0	0.0	0.0	12.0	45.7	0.7	3.7	0.6	1.6
23:00–23:50	C–B	0.0	0.0	0.0	0.0	8.4	20.7	0.7	3.8	0.4	0.0
August 27–28											
17:45–18:35	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18:45–19:15	M	0.0	0.0	0.0	0.0	0.0	0.0	. . .	. . .	. . .	. . .
19:30–20:20	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0	5.6	27.0
20:30–21:00	M	0.0	0.0	. . .	250[f]	. . .	700[f]	. . .	. . .	. . .	. . .
21:00–21:50	C–B	0.0	0.0	43.7	65.3	101.8	91.5	4.4	37.5	7.0	10.5
23:00–23:50	C–B	0.0	0.0	12.2	12.2	206.3	150.0	0.0	40.0	12.9	16.5
02:45–03:15	M	0.0	0.0	. . .	50[f]	. . .	200[f]	. . .	. . .	. . .	. . .
04:45–05:15	M	0.0	0.0	0.0	0.0	. . .	75[f]	. . .	. . .	. . .	. . .
06:00–06:20	M	0.0	0.0	. . .	. . .	0.0	0.0	. . .	. . .	. . .	. . .
October 7											
17:15–18:05	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18:00–18:30	M	0.0	0.0	0.0	0.0	0.0	0.0	. . .	. . .	. . .	. . .
18:45–19:35	C–B	0.0	0.0	0.5	0.0	25.8	46.8	2.6	3.4	0.0	0.0
21:15–22:05	C–B	0.0	0.0	0.6	1.8	8.3	11.1	31.0	11.6	4.7	0.7
November 18											
16:30–17:20	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7
18:00–18:40	C–B	0.0	0.0	8.3	11.5	15.3	5.5	7.0	2.2	. . .	. . .
20:00–20:50	C–B	0.0	0.7	81.0	29.0	2.8	1.4	7.7	1.7	7.8	0.4
22:00–22:50	C–B	0.0	0.0	27.9	11.3	10.0	3.5	15.1	6.8	5.3	1.3

[a] C–B, Clarke–Bumpus sampler; M, ½-metre net.
[b] Tow at 4.5 metres.
[c] Tow at 14.0 metres.
[d] Tow at 50.0 metres.
[e] Tow at 60.0 metres.
[f] Approximate number of all mysids collected.

TABLE II. Vertical distribution of *Mysis relicta* at Station 76e (depth, 46 metres) in Lake Michigan, 1955. Number of sexually differentiated (D) and sexually undifferentiated (U) mysids per 5,000 litres. Clock times indicate the start (at surface) and end (deepest sample) of a series of 5-minute tows spaced about 10 minutes apart.

Date and time (EST)	Type of sampler[a]	Depth (*metres*)											
		Surface		5		10		20		30		38	
		D	U	D	U	D	U	D	U	D	U	D	U
June 30													
18:00–19:00	C–B	0.0	0.0	0.0	00.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20:30–21:30	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.0	38.4	1.8	3.7
23:30–00:30	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.8	18.7	1.2	6.1	0.8	8.8[b]
July 24													
16:15–17:15	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0[c]
17:15–17:55	M	0.0	0.0	0.0	0.0	0.0	0.0[d]	. . .	. . .	. . .	. . .	0.0	0.0[b]
18:15–19:15	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0[b]
19:15–19:55	M	0.0	0.0	0.0	0.0	0.0	0.0[d]	. . .	. . .	. . .	. . .	. . .	50[e]
20:15–21:15	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	75.2	0.0	2.2[b]
21:15–21:55	M	0.1	0.1	0.2	2.5	3.1	16.8[d]	. . .	. . .	. . .	. . .	0.3	3.1
22:45–23:45	C–B	0.0	0.6	7.4	38.4	6.0	40.1	2.5	8.4	0.5	1.5	0.0	0.0[b]
23:40–00:20	M	1.0	16.1	1.2	9.6	1.0	9.2[d]	. . .	. . .	. . .	. . .	0.2	3.4[b]
October 2													
14:00–15:00	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15:15–15:45	M	0.0	0.0	. . .	. . .	. . .	. . .	0.0	0.0[f]	0.0	0.0[g]	. . .	. . .
16:20–17:20	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17:25–18:00	M	0.0	0.0	. . .	. . .	. . .	. . .	0.0	0.0[f]	0.0	0.0[g]	0.0	0.0
18:00–19:00	C–B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	1.1
19:05–19:45	M	0.0	0.0	. . .	. . .	. . .	. . .	0.1	0.1[f]	2.6	3.8[g]	0.1	0.1
20:20–21:20	C–B	0.0	0.0	0.0	0.0	0.0	0.0	2.5	1.3	19.0	24.1	2.2	2.2
21:20–22:00	M	0.0	0.0	. . .	. . .	. . .	. . .	0.1	0.1[f]	0.7	0.9[g]	0.0	0.0
22:30–23:30	C–B	1.4	1.4	1.2	0.0	0.0	0.0	0.0	0.0	2.2	0.0	2.2	0.0

[a] C–B, Clarke–Bumpus sampler; M, ½-metre net.
[b] Tow at 40 metres.
[c] Tow at 45 metres.
[d] Tow at 13 to 15 metres.
[e] Net hit bottom, approximate number of mysids.
[f] Tow at 18 metres.
[g] Tow at 32 metres.

TABLE III. Vertical distribution of *Mysis relicta* at Station 69 (depth, 101 metres) in Lake Huron, August 25–26, 1956. Number of sexually differentiated (D) and sexually undifferentiated (U) mysids per 5,000 litres. Clock times indicate the start (deepest sample) and end (shallowest sample) of a series of 5-minute tows spaced about 10 minutes apart.

Time (EST)	Type of sampler[a]	Depth (*metres*)											
		Surface		5		23		31		50		63	
		D	U	D	U	D	U	D	U	D	U	D	U
19:30–19:40	M	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	53.0	29.0[b]
19:40–20:20	M	. . .	. . .	0.0	0.0	0.0	0.0[c]	0.1	0.0[d]	. . .	. . .	0.2	0.1[e]
20:25–21:00	C–B	. . .	. . .	. . .	. . .	5.4	9.2	2.6	7.1	0.6	2.5	. . .	. . .
21:45–22:30	M	. . .	. . .	0.5	1.5	1.2	6.9	0.0	0.0	. . .	. . .	0.0	0.0
22:30–23:40	C–B	0.0	0.0	0.5	0.0	0.0	7.4	3.0	13.3	. . .	. . .	0.0	3.2[e]
00:15–01:10	C–B	. . .	. . .	0.0	0.0	0.0	2.7	7.0	22.2	. . .	. . .	0.0	0.0
01:15–02:00	C–B	. . .	. . .	0.0	0.0	0.0	8.0	2.1	35.7	. . .	. . .	0.0	0.8
02:10–02:50	C–B	. . .	. . .	0.0	0.0	0.0	3.0	4.5	19.4	0.0	10.0	. . .	. . .
03:15–03:55	C–B	. . .	. . .	0.0	0.0	0.0	0.0	0.8	10.9	0.0	1.9	. . .	. . .
04:00–04:35	C–B	. . .	. . .	. . .	. . .	0.0	0.0	0.0	7.9	1.4	0.0	. . .	. . .
05:00–05:20	C–B	. . .	. . .	. . .	. . .	. . .	. . .	0.0	0.0	1.6	11.1	. . .	. . .
05:30–05:40	C–B	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	0.0	0.0	. . .	. . .

[a] C–B, Clarke–Bumpus sampler; M, ½-metre net.
[b] Bottom tow, 101 metres.
[c] Tow at 27 metres.
[d] Tow at 34 metres.
[e] Tow at 60 metres.

(1952). Eastern Standard Time (EST) was changed to Local Apparent Time (True Sun Time) to facilitate the calculations. These data have been plotted on the graphs of vertical distribution; appropriate corrections were made for cloud cover and moonlight. Light measurements made aboard the *Cisco* on August 25, 1956, agreed to within 2 to 4 foot-candles with Brown's data after corrections for cloud cover.

Additional physical data such as wind, sea state, and cloudiness are entered routinely in the ship's log.

Surface and subsurface water samples were obtained by Nansen bottles. Determinations of dissolved oxygen and pH were conducted aboard the *Cisco*. The unmodified Winkler method was employed for dissolved oxygen and pH was determined by a Hellige colour comparator. Conductivity measurements were made at the laboratory in Ann Arbor, Michigan.

The mysids were separated into 3 groups (females, males, and sexually undifferentiated), on the assumption that individuals within these groups might have physiological differences. The last group consisted of small individuals averaging less than 9 mm long for which sex could not be determined. Males are readily recognized, while they are still small (9 mm), by the presence of a conical lobe (*appendix masculina*) at the distal end of the third segment of the antennular peduncle. As the males become larger the 3rd and 4th pleopods show allometric growth. Females are less easily recognized but the characteristic oöstegites which form the brood pouch make their appearance as outgrowths from the coxal joints of the endopods of the 7th and 8th thoracic limbs when the females are 9 to 10 mm long.

VERTICAL DISTRIBUTION AND MOVEMENTS

DIFFERENCES IN DISTRIBUTION DURING THE DAY AND NIGHT

Numerous collections made at various depths from the surface to the bottom show that *M. relicta* could be taken only in the stratum immediately above the bottom during the day (Tables I and II). Records from other collections not tabulated here show that this stratum was rather thin at depths shallower than 91 m; mysids were seldom found by day 1.8 m above the bottom in this region, although they were abundant 0.6 m above the bottom. As progressively deeper areas were sampled they were captured farther off the bottom—as much as 7 m at 152 m. Small mysids were frequently found farther from the bottom than the large individuals. These observations agree with those of other investigators, although Southern and Gardiner (1932) took small mysids at all depths in Lough Derg in February and March, and Larkin (1948, p. 25) reported that "On rare occasions *Mysis* was observed at the surface in full daylight."

The vertical distribution of *M. relicta* during the night was decidedly different from the daytime distribution, since mysids were taken in the upper strata whenever it was sampled at night. Evidently these vertical movements occur within each 24-hour period. Mysids were collected in the upper strata during 16 nights in Lake Michigan in 1954 and 1955, and on 2 nights in Lake Huron in 1956.

The similarity among the records of night-time distribution of *M. relicta* for

3 different years, at different times during the year, and in two of the Great Lakes indicates that the mysid's vertical movements are regular migrations. The migrations varied somewhat but all had certain common characteristics. Most variability could be explained on the basis of the effects of environmental conditions.

The vertical migration of *M. relicta* resembled that described for Crustacea as a group by Cushing (1951), except *M. relicta* did not migrate upward again at dawn. As will be demonstrated later, light is the major environmental factor which "triggers" and controls these migrations, while thermal conditions interact with and modify the influence of light.

Mysids were not present in the upper strata until late in the evening, usually by 21:00 EST. The greatest aggregation was in or immediately below the metalimnion. Sometimes they migrated through the metalimnion, when first ascending, but later in the night they usually aggregated in this zone and thereafter only a few mysids were above it. On some nights mysids came to the surface, more often they came no nearer than 10 m, and on some occasions only to 20 m below the surface. The distribution tended to become random during early morning, and although the tendency to aggregate in some particular stratum persisted, it was less pronounced than earlier in the night. Capture of fewer mysids toward dawn indicated that some individuals may have returned to the bottom. All mysids disappeared from the upper strata between 03:30 and 06:00 EST. Collections were made at sufficiently close intervals of time and depths to show conclusively that they do not return to the upper layers, even for a short time, at dawn.

Seasonal Change in Timing of Vertical Migrations

The 1954 Lake Michigan data presented an excellent opportunity for a study of seasonal variations in the vertical migrations, since most of the studies were conducted under similar weather conditions, i.e., clear skies, gentle to moderate winds, and good to perfect visibility. The most obvious changes from early summer through late fall were the progressively earlier ascent and later descent (Table I). In June the mysids ascended sometime between 21:00 and 22:00 EST (June 6) and descended between 03:30 and 04:00 EST (June 27, Fig. 1). They migrated upwards around 21:00 EST and descended between 03:50 and 04:30 EST in July (Fig. 2, Table I). Mysids were taken during their ascent on August 7 (Fig. 3) and 27 at approximately 20:00 and 19:45 EST respectively. The time of descent on August 27 was approximately 05:00 EST (Fig. 4). In October (Fig. 5) and November (Fig. 6, Table I) the time of ascent was considerably earlier, 18:45 amd 17:10 EST respectively. The November time of ascent (17:10 EST) is probably somewhat earlier than it should be for this time of year, since the surface light intensity was appreciably reduced by a heavy fog.

Although fewer studies were made in 1955 and data were not obtained on time of descent, the seasonal change in time of ascent was substantiated. Evidently the mysids were ascending about 21:10 EST in late June (Fig. 7, Table II). They were ascending at approximately 20:55 EST in July (Fig. 8), and at 18:50 EST in October (Fig. 9).

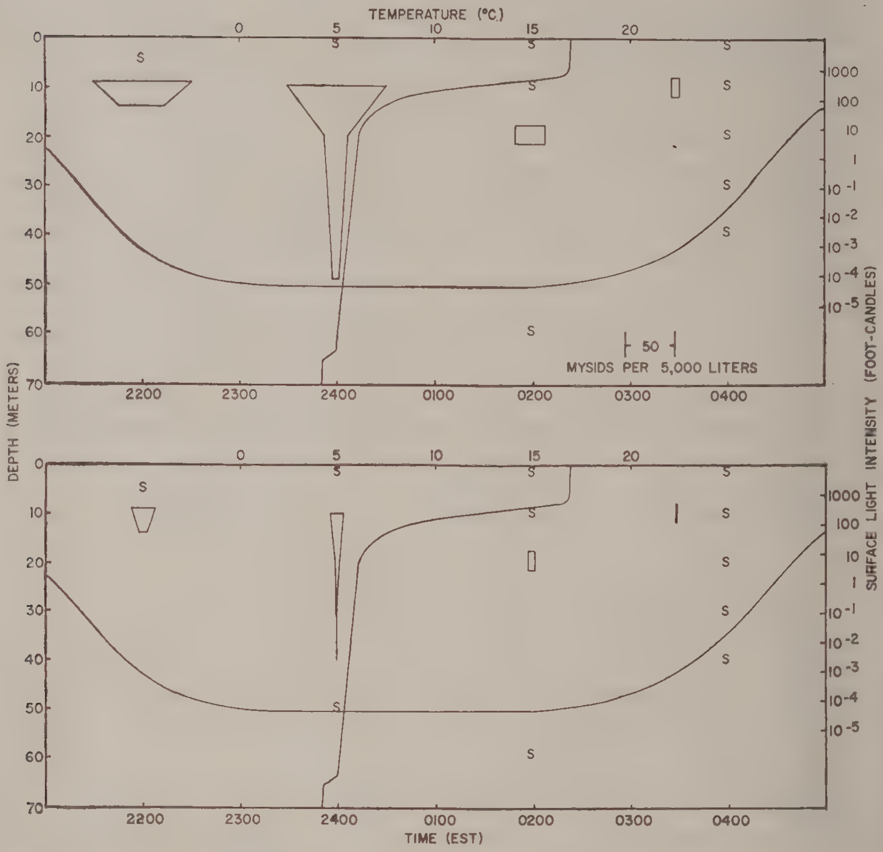

FIG. 1. Vertical distribution of sexually undifferentiated (above) and sexually differentiated (below) mysids at Station 13 in Lake Michigan, June 27–28, 1954. Width of polygon indicates number of mysids per 5,000 litres. "S" indicates a sample that contained no mysids. Temperature is shown by the centre curve. The curve extending from left to right shows the surface light intensity

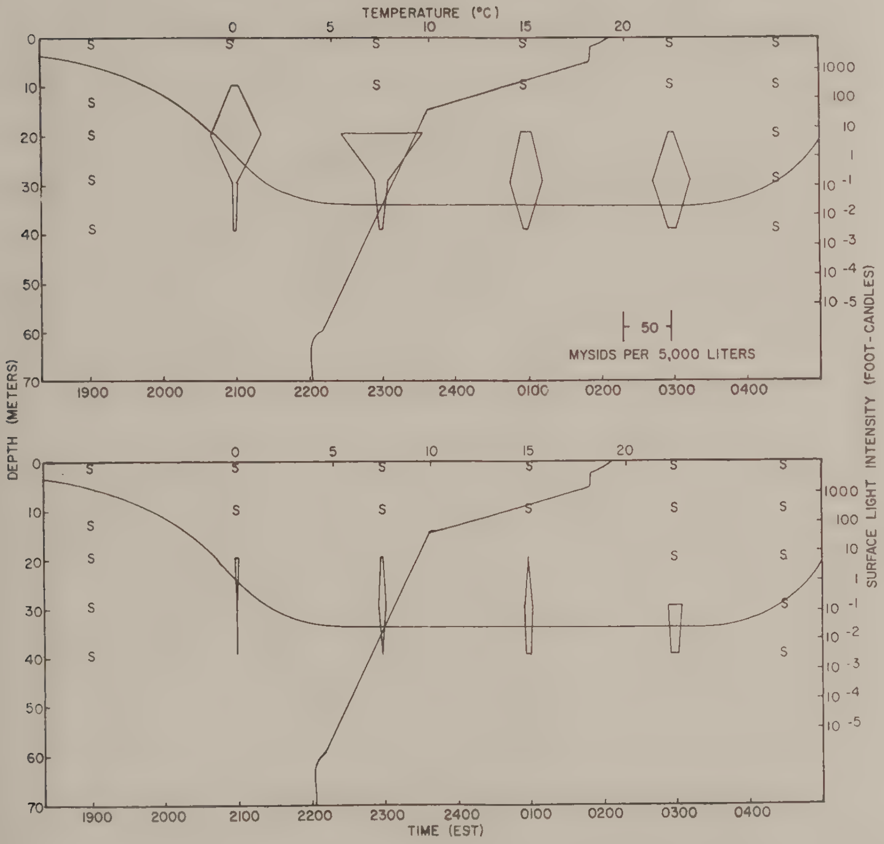

FIG. 2. Vertical distribution of sexually undifferentiated (above) and sexually differentiated (below) mysids at Station 13 in Lake Michigan, July 16–17, 1954. Symbols and units as in Fig. 1.

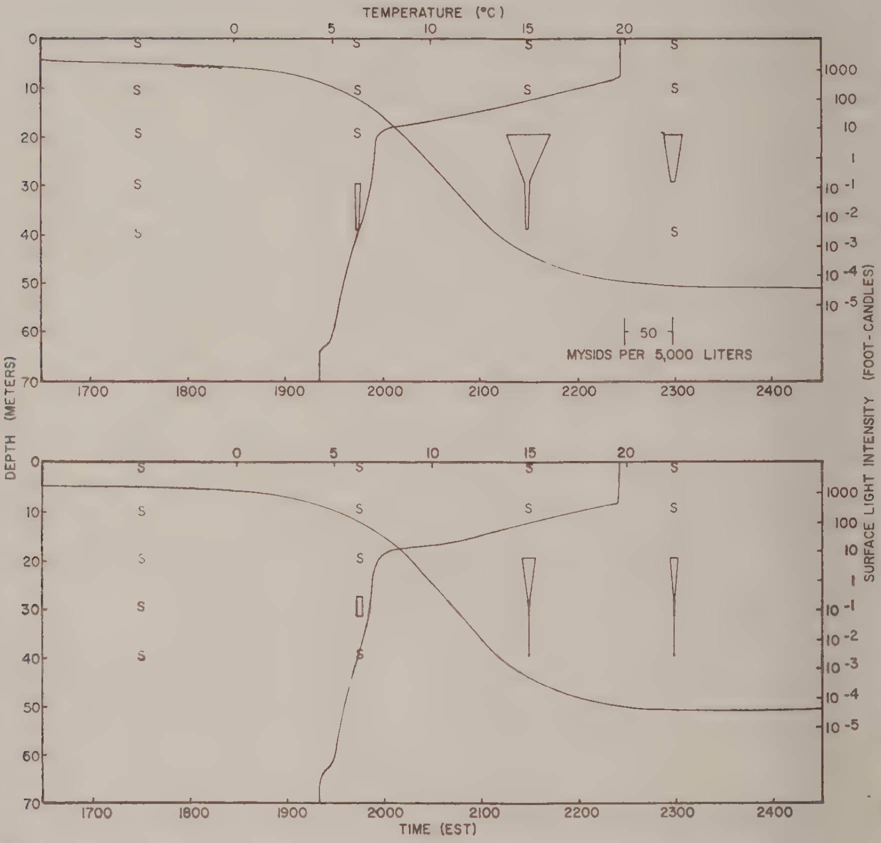

FIG. 3. Vertical distribution of sexually undifferentiated (above) and sexually differentiated (below) mysids at Station 13 in Lake Michigan, August 7, 1954. Symbols and units as in Fig. 1.

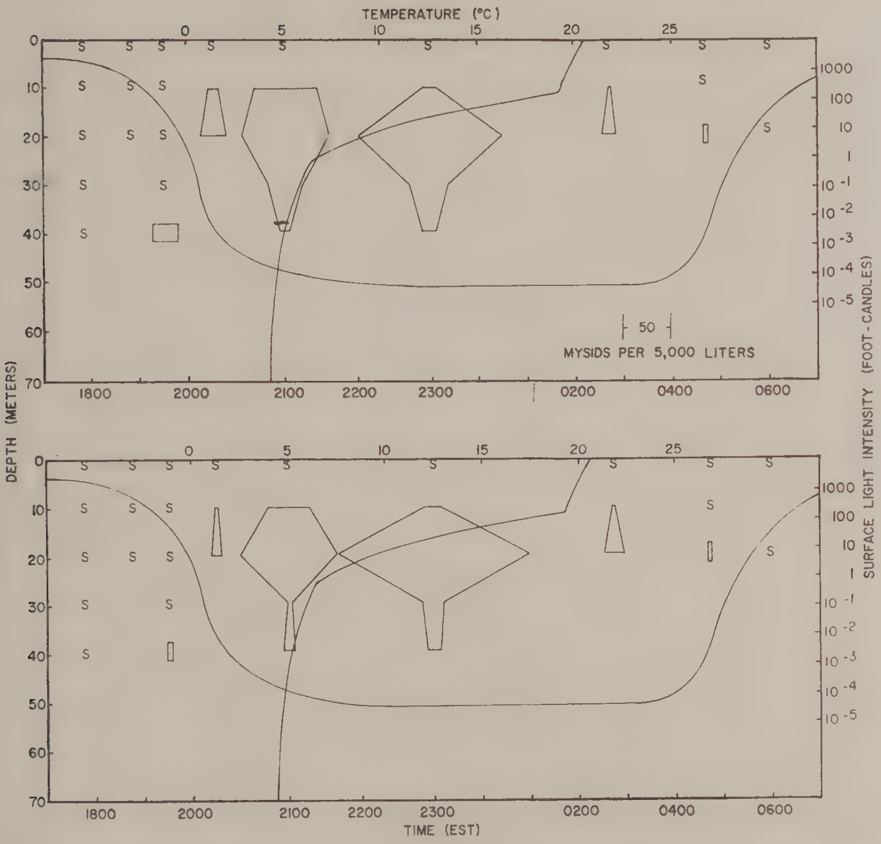

FIG. 4. Vertical distribution of sexually undifferentiated (above) and sexually differentiated (below) mysids at Station 13 in Lake Michigan, August 27–28, 1954. Symbols and units as in Fig. 1.

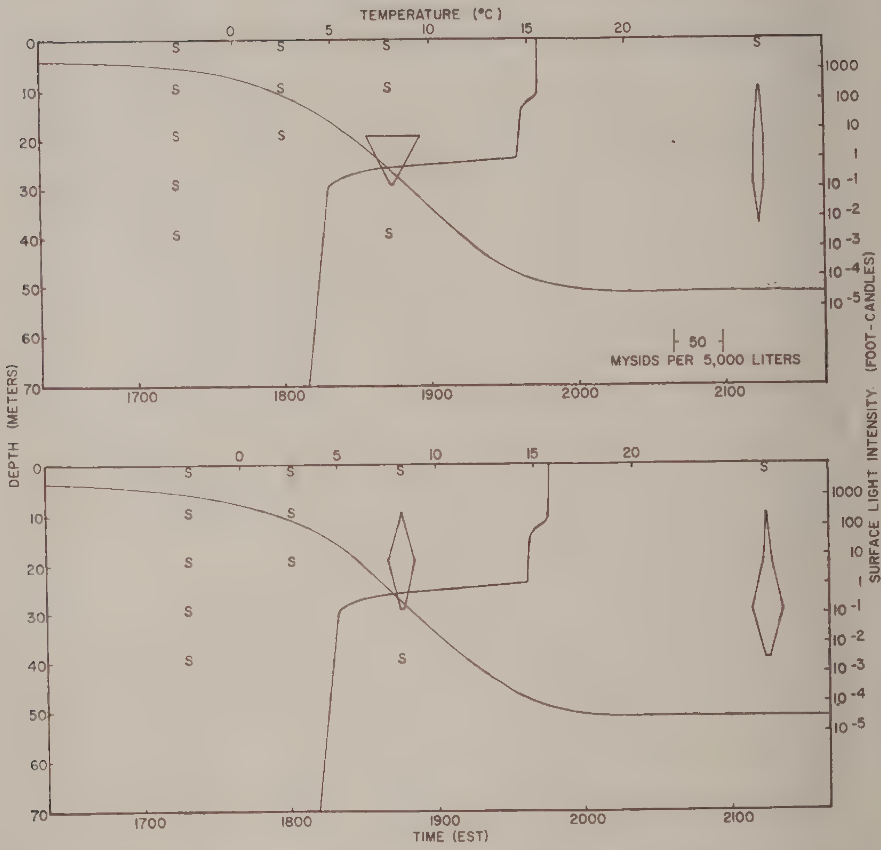

FIG. 5. Vertical distribution of sexually undifferentiated (above) and sexually differentiated (below) mysids at Station 13 in Lake Michigan, October 7, 1954. Symbols and units as in Fig. 1.

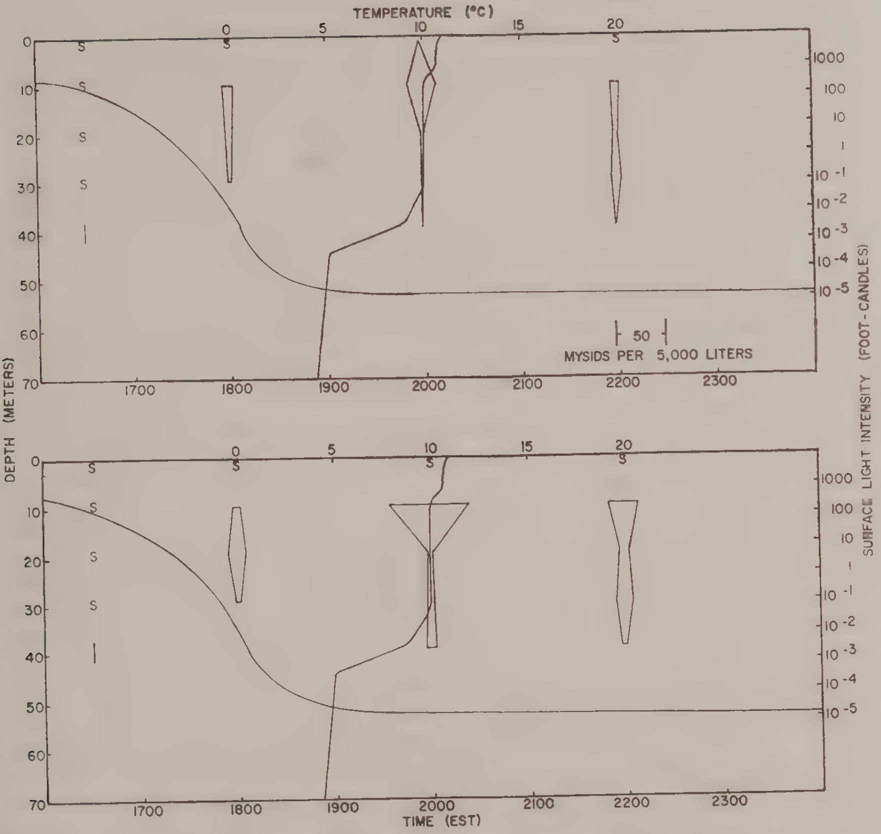

FIG. 6. Vertical distribution of sexually undifferentiated (above) and sexually differentiated (below) mysids at Station 13 in Lake Michigan, November 18, 1954. Symbols and units as in Fig. 1.

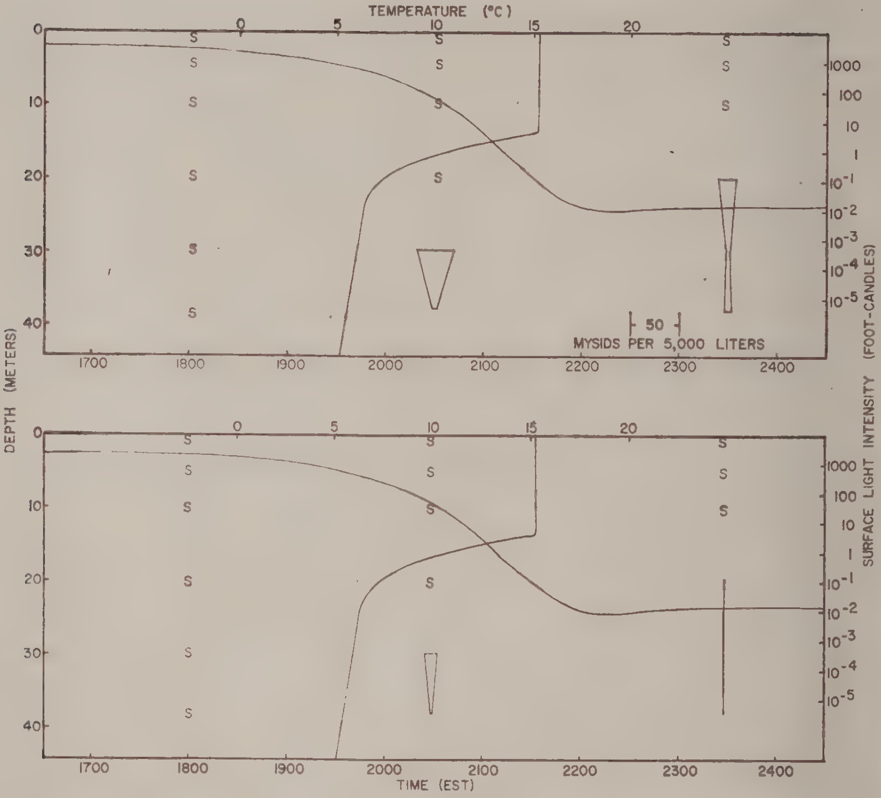

FIG. 7. Vertical distribution of sexually undifferentiated (above) and sexually differentiated (below) mysids at Station 76e in Lake Michigan, June 30, 1955. Symbols and units as in Fig. 1.

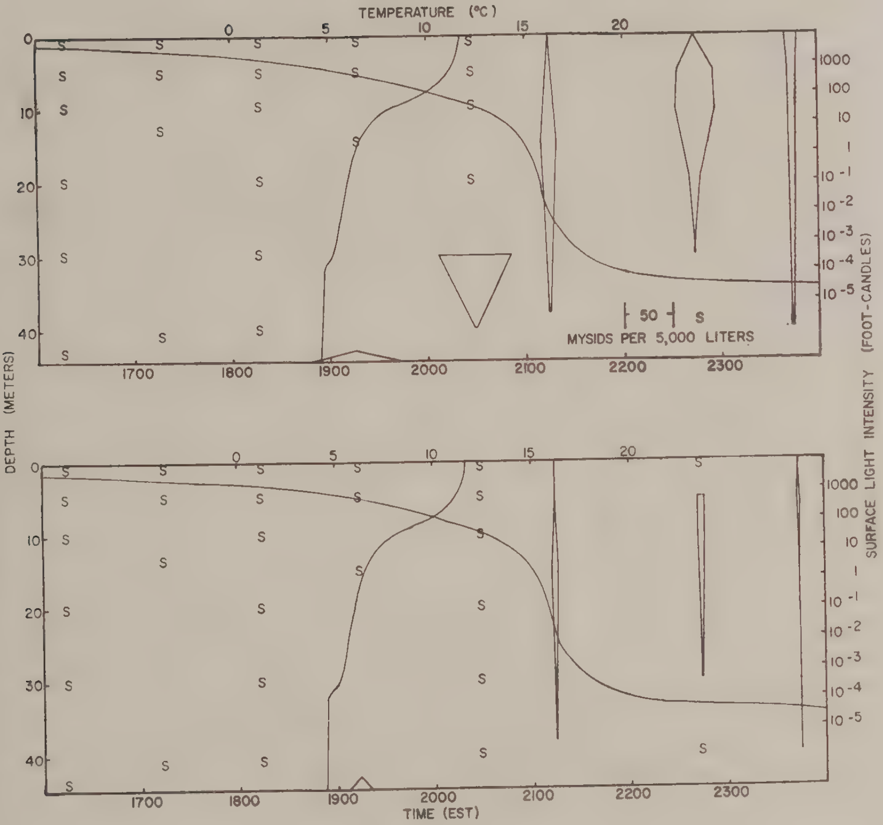

FIG. 8. Vertical distribution of sexually undifferentiated (above) and sexually differentiated (below) mysids at Station 76e in Lake Michigan, July 24, 1955. Symbols and units as in Fig. 1.

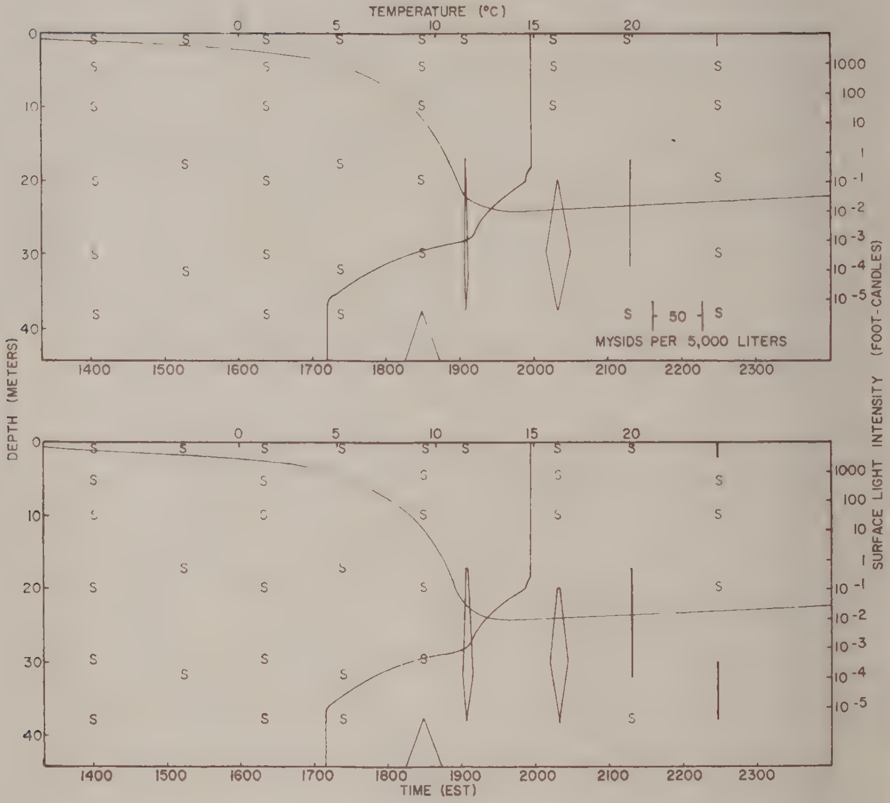

FIG. 9. Vertical distribution of sexually undifferentiated (above) and sexually differentiated (below) mysids at Station 76e in Lake Michigan, October 2, 1955. Symbol and units as in Fig. 1.

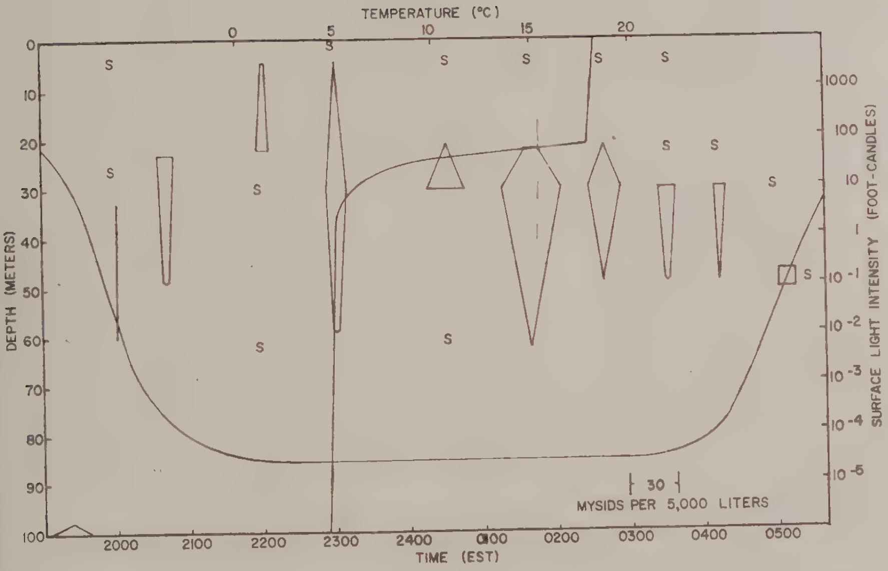

FIG. 10. Vertical distribution of sexually undifferentiated mysids at Station 69 in Lake Huron, August 25–26, 1956 (too few sexually differentiated mysids were collected to be included) Symbols and units as in Fig. 1.

INFLUENCE OF SEX AND AGE ON VERTICAL DISTRIBUTION

The distribution of male and female mysids did not differ noticeably for any of the 1954 or for the earlier 1955 studies. Furthermore, no differences were observed in the behaviour of male and female mysids in the laboratory. The female mysids, however, did not migrate as far off the bottom as the males on October 2, 1955, and they descended almost ½ hour before the males. So few mysids were collected, however, that the significance of this observation is questionable.

The vertical distributions of the small, sexually undifferentiated mysids, and of the larger, sexually differentiated ones, were generally similar, but certain of the samples exhibited exceptions that should be mentioned. On June 6 (Table I) and July 16, 17, 1954 (Fig. 2), it appeared that the small individuals might have migrated upward farther than the large mysids. These differences in distribution can probably be attributed to sampling, especially since the large mysids were very scarce each night. On dates when the numbers of both sexually differentiated and sexually undifferentiated mysids were substantial, the larger individuals were occasionally taken at depths where smaller mysids were absent or vice versa (Fig. 5, 9; Table III). The difference in distribution between large and small mysids on November 18, 1954 (Fig. 6), cannot be explained on the basis of a scarcity of large individuals, since small mysids were taken at the surface, although they comprised only 37% of the total catch, while the large mysids were not found above the 10-metre depth. The available data are, nevertheless, insufficient to establish any consistent differences in the distribution of the small and large individuals. Support for the belief that small individuals may migrate upward slightly earlier as well as farther up than the large mysids may be drawn from the fact that the small ones are found farther off the bottom during the day. Furthermore, other investigators have reported differences between the distribution and behaviour of large and small mysids. Southern and Gardiner (1932), for example, found small mysids at all depths throughout the day in February and March, and Valle (1930) reported that older mysids did not migrate vertically, although the younger ones did.

RATE OF VERTICAL MIGRATIONS

Sampling at frequent intervals on several nights provided data on the rate of ascent and descent. On October 2, 1955 (Table II), *Mysis* first appeared in the samples at 38 m at 18:50 EST. They were not present in samples taken at the surface and at depths of 5, 10, 20 and 30 m prior to 18:50 EST. By 19:15 EST they had reached 18 m. Therefore, the mysids had migrated upwards through a distance of 20 m in 25 minutes at a rate of 0.8 m/min. Similar calculations based on August 27, 1954 (Table I), and July 24, 1955 (Table II), collections gave rates of 0.5 m/min.

The downward movements were similar. On June 28, 1954 (Table I) mysids were at 10 m at 03:30 EST; by 04:40 EST they were not in any of the strata sampled from the surface to 40 m. If it is assumed that they had moved downward no farther than to immediately below 40 m, the estimated rate of descent is 0.4 m/min.

The maximum amplitude of the vertical movements of *M. relicta* is unknown, but it has been established through observations on Lake Huron that it is at least 96 m (Fig. 10). The maximum amplitude recorded for Lake Michigan mysids was 76 m (Table I, June 6). The Lake Michigan night collections were made, however, in areas with depths of 40 to 76 m.

Similarity of Vertical Distribution in Lakes Michigan and Huron

The studies in Lake Michigan on August 27, 1954 (Fig. 4), and in Lake Huron on August 25, 1956 (Fig. 10), show that the vertical distribution was similar in these lakes. The time of ascent coincided to within 10 minutes, i.e., 20:10 and 20:00 EST and the maximum aggregation in both lakes was in the region of the metalimnion. *Mysis* left the upper strata by 05:30 EST in Lake Huron and sometime between 05:15 and 06:20 EST in Lake Michigan.

ENVIRONMENTAL FACTORS OF DISTRIBUTION AND MOVEMENT

The Influence of Light

Analysis of the field data indicates that light conditions govern the distribution of *M. relicta*, and initiate and control the vertical movements. This finding was to be anticipated since light is the only environmental factor in the mysid's habitat that has a regular diurnal fluctuation. In fact, in the deeper areas of Lake Michigan dissolved oxygen, pH, and specific conductance vary but little throughout the year. Furthermore, it was impossible to demonstrate any relationship between these factors and the vertical distribution of the mysids.

Many other investigators have concluded that light is the most important factor controlling the distribution and vertical migrations of zooplankters (Cushing, 1951). Past investigators have lacked convincing evidence of the effects of light on the distribution of mysids, but recently it was demonstrated that light intensity controls the vertical distribution of a marine mysid *Neomysis americana* (Hulburt, 1957).

Light-penetration studies in Lake Huron in 1956 (Beeton, 1958) and in Lake Michigan on May 7, 1958 (unpublished data), showed that sufficient light, of a suitable wave-band for mysid vision, penetrated into the deeper areas of these lakes. *M. relicta* has a peak sensitivity to light at a wave-length of 515 mμ and can react to a light intensity of 9.0×10^{-6} foot-candle (Beeton, 1959). Light with a wave-band of 490 mμ to 540 mμ penetrated to the greatest depth in both lakes. Four foot-candles of blue-green light (490-540 mμ) were recorded at 40 m in Lake Huron on August 25, 1956, at 16:00 EST. The approximate extinction coefficient for light with this wave-band in Lake Huron is 0.11; therefore, according to Lambert's Law, 5.44×10^{-3} ft-candle of light should penetrate to a depth of

100 m even this late in the day. The approximate extinction coefficient for this wave-band in Lake Michigan, May 7, 1958, was 0.166. From measurements made at 15 m it was calculated that 4.37×10^{-5} ft-candle of light would penetrate to 100 m. Secchi-disc measurements on May 7, 1958, were appreciably lower than those usually observed in Lake Michigan. Consequently, the extinction coefficient determined on May 7, 1958, is probably higher than normal.

Although agreement has been general that light is the most important environmental factor controlling the vertical migrations of zooplankters, opinions have differed widely as to the way in which it exerts its influence. Among the hypotheses advanced are: animals maintain an optimum light intensity; they respond to changing intensities; they react photonegatively or photopositively to particular intensities; their negative geotactic response is inhibited. It has been suggested also that samples may be biased at higher illuminations because the mysids can see and avoid the net. Most of the recent hypotheses have held that animals move in order to maintain an optimum light intensity, or respond to changes in light intensity. Actually the hypotheses based on an optimum intensity and on a change in intensity are to a degree inseparable, since changes in light intensity would force the zooplankters to move in order to remain in the optimum zone. None of these hypotheses, however, satisfactorily explains all aspects of the vertical migration of *M. relicta*.

Evidence that changes in light intensity "trigger" the upward and downward movements of *M. relicta* comes from the close correlation, already described, between the length of day, and the times of ascent and descent. Furthermore, the computations of light intensity for the periods of ascent and descent show that regardless of the time of year the mysids had started to ascend and descend when the intensity reached certain definite levels. They were ascending when the surface light intensity was decreasing from 15 to 1 ft-candle at approximately 5.6×10^{-1} ft-candle per minute, and descending when it was increasing from 10^{-3} to 10^{-2} ft-candle at approximately 3.0×10^{-3} to 1.2×10^{-1} ft-candle/min. These movements in response to changing intensities cannot be attributed to an inability on the part of the mysids to adapt to changes of the above magnitudes, since it has been demonstrated that *M. relicta* can readily adapt to changes of this amount in less than a minute (Beeton, 1959).

The vertical migrations of the mysids may be due to their hypersensitivity to light. The difference in the daytime distribution between areas shallower than 91 m and those 152 m deep may be the result of this hypersensitivity. The mysids are taken considerably farther off the bottom in the deeper areas possibly because the light intensity is much less than in shallow water and hence within their optimum range. This hypersensitivity could restrict them to the bottom during the day, but they should be able to move into upper levels when the intensity decreases to their optimum range. Conversely, an increase of light intensity at dawn should force them to the bottom. The rapid rates of ascent and descent challenge the validity of this hypothesis, however, and suggest a positive response to decreasing light intensities and a negative response to increasing intensities. Furthermore, if the mysids were merely seeking an optimum intensity or exhibiting a positive phototaxis to weak light, they should return toward the upper strata at dawn, like many other zooplankters (Wells, in press; Ullyott, 1939). The failure of mysids to move upward at dawn suggests a possible reversal of the phototactic sign from positive to negative during the night. Evidence for such a reversal comes from laboratory studies which showed that the mysids were photopositive to a weak light unless they had been in the dark for a number of hours; then they were photonegative (Beeton, 1959). Limited observations from this same study indicate that *M. relicta* also responds photonegatively to increases in light intensity.

The restricted vertical distribution of mysids on nights when the moonlight was bright provides evidence that light controls their distribution. On these nights the mysids usually did not migrate higher than the 20-metre level. This behaviour was observed on July 16, 1954 (Fig. 2), and June 30, 1955 (Fig. 7), when the mysids were concentrated 5 to 10 m below the metalimnion. The surface light intensity did not fluctuate appreciably after sunset on either of these nights since the moon was rising during sunset.

Evidence that moonlight may cause downward movement as well as limit upward movement comes from the observations on October 2, 1955 (Fig. 9). When the mysids first ascended on that date they migrated through the metalimnion into the 18-metre stratum, but later, as the illumination from the full moon increased, they descended. By 22:30 to 23:30 EST only 6 individuals were captured in 6 plankton tows made within the upper 40 m. The change in light intensity at this time was comparable to that occurring when the mysids normally descended, even though the rate of change was considerably less. The illumination on the surface from the full moon increased from 1.1×10^{-2} ft-candle at 20:00 EST to 2.5×10^{-2} ft-candle at 24:00 EST, as the moon's altitude changed from 28° to 53°. (These figures are based on calculations made by Russel (1916) that the illumination from a full moon at an altitude of 65° is approximately 3×10^{-2} ft-candle.) This increase in light intensity seems slight but consideration should be given to the fact that a greater percentage of the moonlight would have penetrated the water when the moon's altitude was 53° than when the altitude was 28°. Consequently, the actual increase in light intensity was greater than indicated.

THE INFLUENCE OF TEMPERATURE

The vertical distribution of *M. relicta* was influenced also by water temperatures. Under certain conditions temperature modified the mysids' response to light and was even the major environmental factor limiting their vertical distribution during hours of minimum light intensity. Both temperature gradients and absolute values can affect the distribution of mysids.

When the temperature gradients were 2.0° and 1.67°C per metre in the metalimnion (Fig. 1, 3), the mysid did not migrate through the discontinuity layer. The limits of effectiveness of temperature gradients become evident when the maximum change in temperature in the metalimnion is somewhere between 0.66° to 0.94°C per metre. When changes were of this magnitude some mysids swam through the metalimnion as they ascended, but most remained in and below it and later at night, under minimum light intensity, those that had penetrated into the epilimnion returned to join the concentration in or immediately below the metalimnion. Night-time movements of this type were observed on August 27 (Fig. 4), and October 7, 1954 (Fig. 5), and August 25, 1956 (Fig. 10).

On August 27, 1954 (Fig. 4) the mysids migrated through the metalimnion into 19°C water, but later in the night only a few individuals were taken in the warm waters of the epilimnion. Evidently most of the mysids retreated to the metalimnion. This behaviour suggests that higher temperatures in the epilimnion may be important in limiting the vertical distribution. Mundie (1959), however, apparently collected *M. relicta* in the warm surface waters of Lac la Ronge throughout the night.

When the metalimnion was absent or poorly defined and temperatures were low at all levels, on June 6 (gradient less than 0.2°C m and surface temperature 11°C, Table I) and on November 18, 1954 (Fig. 6), the mysids migrated to the surface. On July 24, 1955 (Fig. 8), when upwelling at Station 76e disrupted the thermal stratification, mysids migrated into the 11.7°C surface water.

SUMMARY

The diurnal changes in the vertical distribution of *M. relicta* in Lakes Michigan and Huron are the result of regular vertical migrations. These migrations are basically initiated and controlled by changing light conditions, but thermal conditions may modify the influence of light.

The mysids are hypersensitive to light and favour a low optimum intensity. Consequently, they are concentrated near the bottom during the day. They migrate upward at sunset as the light intensity drops, possibly because of a positive reaction to a decreasing light intensity. Their subsequent aggregation in certain strata is determined by their response to the existing light and thermal conditions. During the night the mysids become photonegative. They descend at dawn in response to increasing light intensity.

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SCALE AND SCUTE DEVELOPMENT OF THE CARANGID FISH *CARANX CRYSOS* (MITCHILL)

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In the genus *Caranx*, a scute is recognized as a modified scale in the straight part of the lateral line (fig. 1). Description of the scute and its development in *Caranx crysos* (Mitchill) is recorded in this study. The scute is larger, thicker, and harder than other body scales, and its posterior margin terminates in a spine or a point. It contains a portion of the lateral line canal in a tube having its anterior opening on the outer surface, its posterior opening on the inner surface, and generally a pair of shorter tubes whose anterior openings are confluent with the posterior opening of the central tube and whose posterior openings are on the interior surface of the scute near its posterior margin. These latter openings furnish contact with the environment for this part of the lateral line system—the posterior opening of the central tube joins the anterior opening on the external but embedded portion of the next posterior scute.

The numbers of scutes vary. Intraspecifically, they vary bilaterally; they vary up to certain body lengths with growth of the fish (the scutes are in the process of formation to about 100 mm. standard length in *Caranx crysos*, and fish smaller than this size usually have less than the adult complement of scutes); and they vary, usually within predictable limits, between adult fish of the species. Interspecifically, their variation has been utilized taxonomically—pairs or groups of selected species can be separated by the distinct ranges of their adult complement of scutes.

The recorded numbers of scutes counted may vary according to the individual who counts them. One noted worker on *Caranx* systematics (Nichols 1920: 30), after a brief discussion of scute counts and their variation, concluded "that the personal equation enters into their count somewhat." To promote comparable counts by different workers, an exacting definition has been employed: Primarily, counts are made to include all scutes from the most anterior to the most posterior completely developed scute. A completely developed scute either has a spine at its posterior margin or its posterior margin is angled to a point with the angle formed being not greater than 120°. The adult complement of scutes of *Caranx crysos* ranges from about 46 to 56 (Berry 1959).

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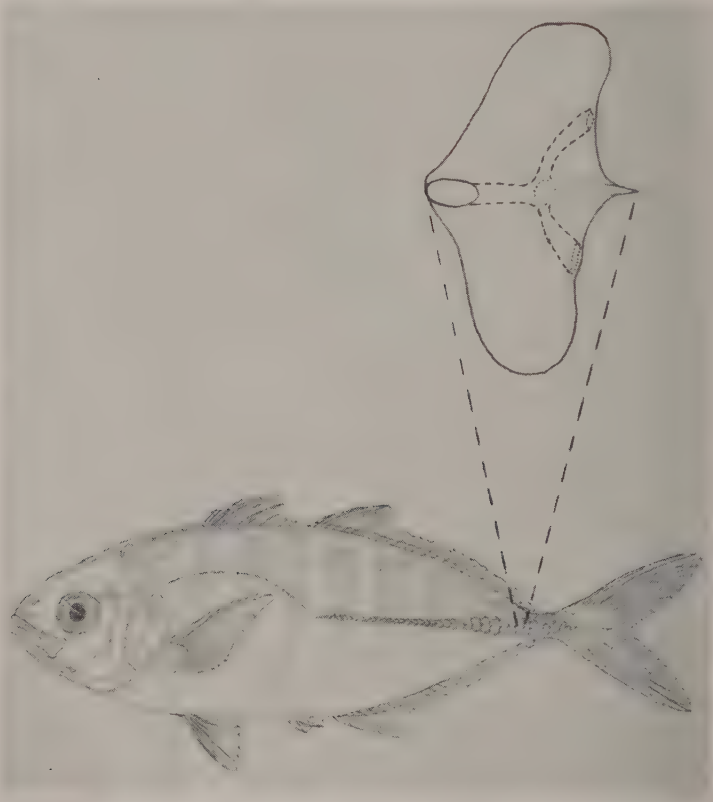

Fig. 1. Relative position of a completely developed scute on a specimen of *Caranx crysos* of 82.5 mm. standard length. Dotted lines show the lateral line tubes and their openings on the internal surface of the scute.

METHODS

Several hundred specimens of *Caranx crysos* from 5.4 to 438 mm. standard length (S.L.) were examined. A number of these were stained with alizarin and cleared with potassium hydroxide, and some were depigmented with hydrogen peroxide.

Observations on the formation and development of scales and scutes apply only to those scales and scutes that are at least partly ossified (and which consequently stain red with alizarine).

All body lengths are standard lengths (from tip of snout to end of caudal base). The size of the smallest specimen available that depicted a particular ontogenetic feature is used as the size of occurrence or development of that feature. There is some slight variation, however, in the body size at the acquisition of the various characters.

Terminology of position or direction of the scales or scutes accords with the normal position of the scale on the fish: outer refers to the surface of the scale away from the body of the fish, inner refers to that next to the body, dorsal refers to the aspect of the scale that normally is directed toward the dorsal part of the fish.

SEQUENCE OF SCALE FORMATION

Scale formation is depicted diagramatically in figure 2.

At 9.8 mm. and smaller sizes no scales have formed.

At 10.4 mm. scales (potential scutes) along the straight part of the lateral line have formed.

At 12.5 mm. a few scales have formed in the curved part of the lateral line adjacent to the straight lateral line.

At 13.1 mm. scales along the entire portion of the curved part of the lateral line have formed, and a few small rounded scales have formed above and below the mid-posterior part of the lateral line.

At 14.4 mm. scales have formed in single rows above and below the straight lateral line.

At 16.0 mm. scales in the row above and below the straight lateral line have developed circuli, a few scales have formed next to these, and a few scales have formed above and below the curved lateral line.

At 16.7 mm. additional scales have begun to form over the sides of the body.

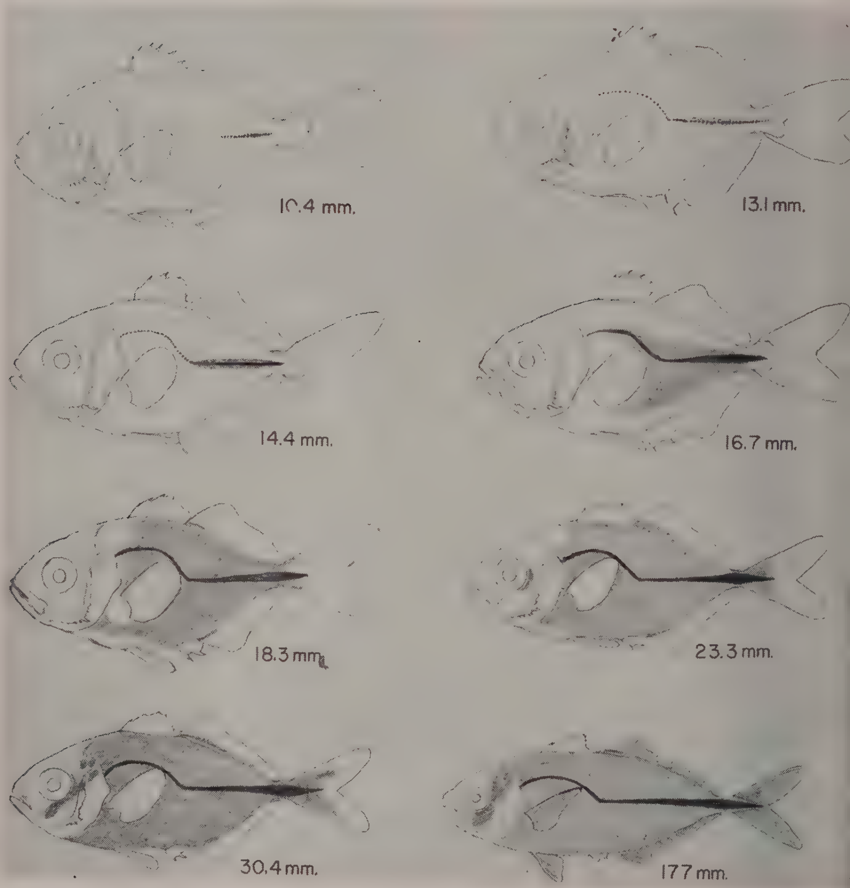
10.4 mm.
13.1 mm.
14.4 mm.
16.7 mm.
18.3 mm.
23.3 mm.
30.4 mm.
177 mm.

Fig. 2. General sequence of appearance and development of scales in *Caranx crysos*. Black areas represent scales and scutes in the lateral line. Shaded areas represent scales of the body, fins, and head. Sizes are in millimeters of standard length.

At 18.3 mm. scales have covered the body except for small areas anterior to the first dorsal and the pectoral fins, on the chest, and on the end of the caudal base; and scales occur on the basal sheath of the soft dorsal and anal fins.

At 19.6 mm. the straight part of the lateral line has extended onto the caudal fin.

At 21.7 mm. a small elongated patch of scales has formed posterior to the eye, and scales have extended onto the caudal fin.

At 23.3 mm. scales have essentially covered the body.

At 30.4 mm. scales are present on the head behind and below the eye and on the posterior part of the head.

At 43.5 mm. scale rows are formed on the membranes between the anterior dorsal and anal softrays.

At 59 mm. scales are on the caudal fin to more than one-half the distance to the end.

At 70.5 mm. scales have started to form on the pectoral and pelvic fins.

At 177 mm. scales are present on all parts of the fish except the margins of the paired and soft fins, the spinous dorsal and anal fins, the dorsal and anterior part of the head, the snout and jaws, the interopercle and subopercle, and the major lower portions of the preoperculum and operculum. This represents the ultimate squamation in the adult.

Scute Development

The lateral line scales and potential scutes are more highly developed in the region of the anterior part of the caudal peduncle than in other portions of the lateral line. Descriptions below are of scales and scutes taken from this area. Scales and scutes anterior and posterior to this area are progressively less developed.

The stages of development are shown in figure 3.

Specimens 9.8 mm. and smaller lack scales.

At 10.4 mm. the scales are convex anteriorly and concave posteriorly. An opening in the scale base may be present or forming. Slight thickenings extending out from the base are present on the dorsal and ventral margins of the outer surface (fig. 3, A and B).

At 10.7 mm. the dorsal and ventral thickenings have become ridge-like extending further above the base (C).

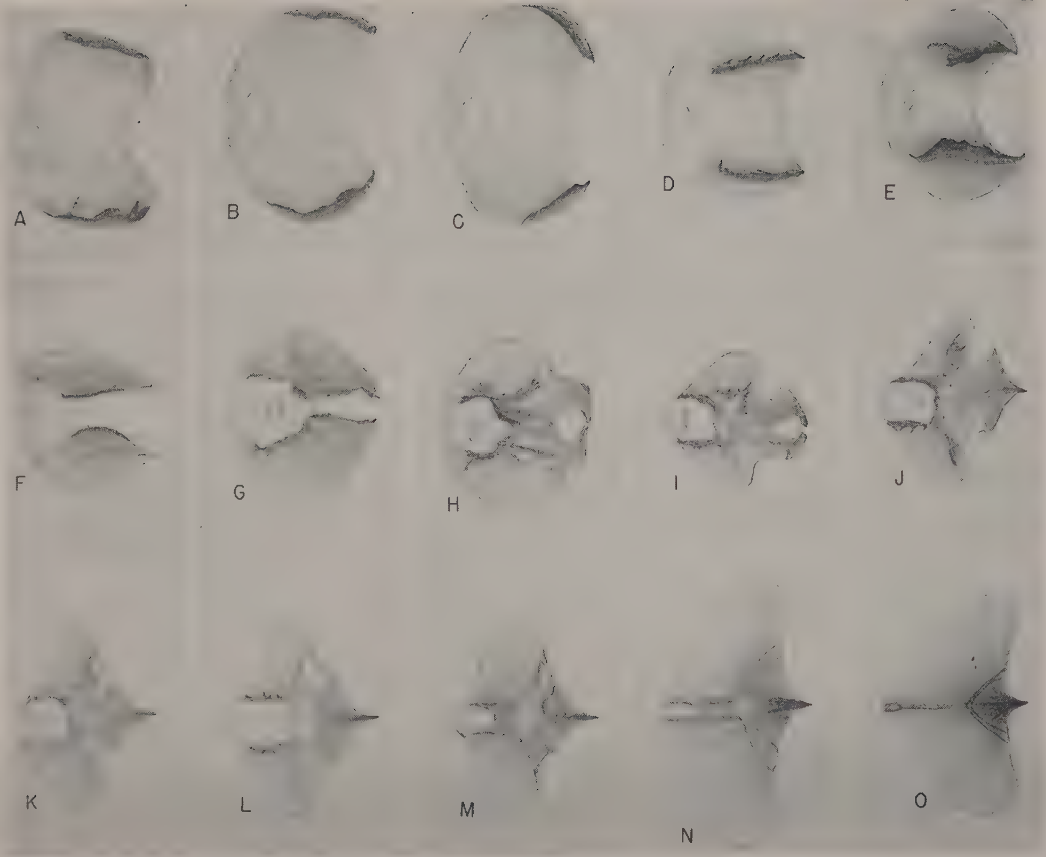
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O

Fig. 3. Scute formation in *Caranx crysos*. The forming and the completely developed scutes are in alpha-

By 12.5 mm. the ridges have converged toward the midline of the scale (D).

At 13.4 mm. the distal margins of the ridges have started bending toward each other (E).

At 14.4 mm. and 16.0 mm. the ridges have bent closer to each other over the outer exposed portion of the base (F and G).

At 16.7 mm. the ridges have joined along part of their confluent edges, and the anterior opening of the central tube has formed (H).

At 18.3 mm. projections extend anterio-laterally from the posterior ends of the ridges (I). On some more advanced scales at this size the ends of these projections become pointed and begin to turn under the plane of the outer portion of this part of the scale, and the posterior ends of the joined ridges have fused to form the spine (J). This latter condition (J) demonstrates a completely developed scute, by definition and by enumeration, while the other scale (I), depicted from the same fish, does not.

At 20.3 mm. the posterior margin of the scute has filled out, and elements on the inner surface are turning in posterio-medially to form the secondary tubes (K).

At 23.3 mm. the scute structure is essentially completed (L).

With continued growth the tubes and their openings become relatively smaller, as is depicted at 43.5 mm. (M), 107 mm. (N), and 177 mm. (O).

On some scutes of fish between about 25 and 35 mm., a smaller secondary spine may form along the outer anterior portion of the main posterior spine, but this secondary spine is temporary and is probably overgrown by the thickening of the scale.

On the scutes of some fish between about 140 and 160 mm., small flattened spines are formed on the posterior margin over the openings of the lateral tubes, but these also do not persist.

The maximum dorso-ventral measurements or diameters of the scales and scutes illustrated in figure 3 are: A, 0.095 mm.; B, 0.088 mm.; C, 0.090 mm.; D, 0.14 mm.; E, 0.19 mm.; F, 0.19 mm.; G, 0.29 mm.; H, 0.26 mm.; I, 0.39 mm.; J, 0.40 mm.; K, 0.59 mm.; L, 1.19 mm.; M, 1.72 mm.; N, 4.73 mm.; O, 6.67 mm.

There are three principal results of this study. It supports the generalization of Lowenstein (1957) that the development of the sensory papillae and the canal systems of the lateral line appears to be related to the mode of life and habitat of the species, with free-swimming forms *[such as Caranx crysos]*, in which the body is continuously exposed to the action of relative water movement, usually having the canal system well-developed as protection for the delicate sensory papillae. It furnishes another potentially discriminant character for systematic consideration. It affords comprehension of an interesting and perhaps unique ontogenetic process.

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FISHERIES AND THE FUTURE

Vernon E. Brock[1]

The population of the world is increasing rapidly nd the concurrent demands on the natural resources f this planet grow even faster. The exploitation of atural resources is accelerated not only because there re more people, but because they desire, and to ome degree attain, higher standards of living.

Among the natural resources subject to accelerated arvest are the fisheries. The use of the world fisheries n a fashion best designed to sustain yields of increasing agnitude in future years will generate a series of roblems of great difficulty and interest. I propose o speculate about the nature of these problems and ome possible solutions.

Fisheries belong to a group of natural resources hat are living and, by virtue of being alive, are self-enewing. In contrast, most mineral resources are ot being regenerated—at least at a sufficiently high ate to effectively postpone the date of their exhausion. Some nonliving resources, such as soil or water, re renewed.

For the renewable resources, both living and non-iving, the harvest must not, on a sustained basis, xceed the rate of replenishment. The replenishment f that taken by harvest is analogous to interest, but or most of the living resources it, unlike interest, annot be effectively used to increase capital. If it s not used, it disappears and the failure to recognize his fact has distorted some thinking concerning the anagement of renewable resources.

Nonrenewable natural resources produce no interest; our use constitutes a consumption of capital, with he likelihood of its ultimate exhaustion. Patterns f use that tend to recirculate would serve to extend he supply as would the use of substitutes. Ultimately, on a self-contained earth, with the energy of the sun as its only significant extraterrestrial import, ll resources must be renewable; minerals must be irculated rather than dissipated. Of course, the importation of minerals from extraterrestrial sources would reduce this requirement.

The problems of management of the renewable resources, such as fisheries, are essentially problems of controlling the magnitude of harvests so that replenishment by reproduction is not consistently exceeded and of managing the resource and the associated environment so as to maximize replenishment.

Insofar as our needs are satisfied by yields below that added annually by reproduction and recruitment, the task of managing a fishery is one of monitoring the effects of exploitation, to see if indeed the yields are less than can be safely sustained. In addition, work designed to reduce the effort of harvest or to increase the utility of the catch may be desirable under some circumstances.

Those fisheries which are exploited at their highest maximum sustained yield, and thus should be regulated, are the fully exploited or "mature" fisheries. Such fisheries are in the minority; most of the existing fisheries can apparently sustain some increases in yields, while others are but lightly fished.

Implicit in the statement that mature fisheries should be regulated is the assumption that it is a legitimate activity of government to manage a resource so as to sustain its productivity. If the responsibility for fishery regulation is a governmental responsibility, then obviously it is also a governmental responsibility to measure adequately the consequence of regulation. If such measures are inadequate or lacking, justification for regulation disappears. Regulation without adequate evaluation of the consequences is not uncommon, especially at the state government level.

Since many fisheries are neither within the jurisdiction of any one nation nor exploited by citizens of one nation, management may involve treaties among the governments concerned. These treaties usually establish an international commission to manage the fishery or to handle the various questions which arise concerning its exploitation. The international regulation of fisheries by commissions or other analogous groups will certainly increase in the future.

THE NATURE OF THE SEA FISHERIES

Fisheries are a food-harvesting activity akin, in certain respects, to agriculture. Some portions of the catch are used for needs other than food (oils, stock feeds, fertilizers) which, in a fashion, again parallels the use of certain agricultural products.

While the production of the world fisheries is increasing, the yields, as indicated earlier, can doubtless be yet increased by many times, principally perhaps by the development of fisheries for those organisms lightly or not presently exploited.

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The 1958 yield of world fisheries, both freshwater and marine, was about 33 million metric tons, substantially less than world meat production and far less than the total yield of animal protein from land. Galtsoff (1952) gave the following yields for certain fisheries:

TABLE 1

YIELDS OF FISHERIES FOR SELECTED AREAS

Area	Lb/Yr/Acre
Sea of Azov	70.3
Sea of Japan	25.3
North Sea	21.9
Mediterranean	13.4
Atlantic	.6
Pacific	.5

Nelson Marshall (1951) estimates that the yields of the fisheries of North Carolina contain only .08 to .06 per cent of the carbon initially bound up by marine plants. These yields vary from 8 to 21 pounds per year per acre. In terms of an efficient utilization of marine productivity, fisheries do very poorly. However, this is due to the nature of the community of living organisms of which the fish are a part.

The economy of the biotic community is based on the growth of plants. Feeding on the plants are various kinds of herbivorous animals, and in turn the herbivores are eaten by predators which may also be prey for yet others. The generation of foodstuffs by feeding and growth drops rapidly from the plants to the herbivores, and from the herbivores to the predators, being least for the climax predators at the end of the food chain. This is true because food dissipated as energy cannot be used for growth and a portion of what is eaten is not digested.

The majority of our more important commercial fish species are predators and are for that reason among the less abundant species in the sea. Their size, their ease of capture, and their palatability are reasons for their being the object of fisheries.

Fishing differs in a fundamental way from farming in that a fisherman harvests but does not cultivate. Progress in fisheries has been, in the main, improvements in methods for harvesting. Such improvements are essential for the expansion of the fisheries and for their profitable pursuit, but will not give any increase in yield for mature fisheries. For such fisheries, improvements may permit the catch to be taken for less cost and/or in less time.

A POSSIBLE PATTERN OF SEA FISHERIES DEVELOPMENT

As our demands for food from the sea increase, additional fisheries will tend to become mature and to acquire thereby a body of regulations designed to control the catch. Ultimately, it may become desirable to consider means of increasing the yield beyond the point of the maximum sustained yield obtained from the unmodified environment. To do this we must increase the productivity of our fisheries and this in turn implies some changes, carefully designed and controlled, in the environment. These changes can be made in either the physiochemical environment or in the biological one, the biotic community. Let us consider this latter suggestion first.

A simple approach would be to fish the lower trophic levels and to fish less selectively; in short, to harvest in a general, rather than a specific way. It may be suggested that the supply of foodstuffs generated in the sea tends to remain more uniform than the individual abundance of the organisms generating and sustained by it. Therefore a broader harvesting base would result in yields less subject to fluctuations than those of individual species, and by being broader, would produce yields of greater magnitude. However, much of the catch may be of little value.

It may be more effective, however, to fish in a fashion that would improve the biotic community as a habitat for the more desirable species. A pattern of fishing designed to reduce predators and competitors and increase the prey of the desired species would have this effect. By such tactics, we would, in a sense, be cultivating the sea and would approach the pattern of agriculture. The magnitude of the maximum sustained yield of the desirable species should, thereby, be increased.

The manipulation of the biotic community require the development of fishing techniques of sufficien scope and power to substantially reduce the populations of presently unwanted and comparatively valueless species. While such techniques are certainly no at hand, perhaps some now in their beginnings, suc as electrofishing, will provide adequate means, singl or in combination with others, to accomplish this.

Should we succeed in manipulating the biologica environment to an adequate degree, further increase in the yield of fisheries may be attained through th development of high yield varieties by selective breeding. Such an accomplishment, together with the manipulation of the biotic community, would thus add tw important techniques of agriculture to the management of fisheries. This would represent a technologica level equivalent to cattle ranching.

If we could change or manipulate the sea itself i some fashion, the effect on fisheries could be enormou Some slight shifting of the flow of ocean curren would change water temperature and the charact of the environment profoundly. The stabilization current flow to prevent long or short term shifts ma be as important.

The decade of lower than normal sea temperatur off southern California, through the late ninete forties and fifties, has been considered as an importa factor in the virtual disappearance of the Califor sardine and the collapse of its fishery. The incursi of warm water off Peru, the "El Nino," has a destru tive effect on the marine biota of this area, oft causing a tremendous reduction in the guano bi population by reason of the unavailability of Peruvian anchovy, its principal food.

While the warm surface waters of the trop supply an ideal environment for life, the loss utrient elements to the depths where light is insuficient for the growth of plants often makes the upper unlit waters comparatively barren. A means of bringng the waters from the dark, cool depths to the urface would restore the lost nutrients and thereby ultiply the productivity of the surface waters.

In a sense, the manipulation of the physical enironment of the sea itself, together with the maniulation of the biological environment and of the enetic constitution of the stock of organisms subject to fishery, would give the fisherman the major techiques of the farmer, and fisheries would begin to pproach the technological level of agriculture.

I have discussed some ways in which the producivity of the sea may be increased; let us consider ome means of accomplishing these ends. What do we eed to know, and what must we be able to do to bring bout such changes? For some the magnitude of the ask is so great that I can suggest very little as to ow we may go about it. I am like a cave man atempting to plan a space ship—the plans are likely o be rather vague.

Presently our ability to manage a fishery is retricted to the regulations of fishing effort, useful for ature fisheries. The usefulness of these regulations, owever, is dependent on how well we can establish he maximum sustained yield for a fishery. This is a figure arrived at by the examination of the effects f catches made in the past on the stock and on reruitment. If variations other than fishing have little effect on recruitment, the magnitude of this figure may adequately be established. However, where reruitment responds significantly to environmental fluctuations as well as to the number of spawning fish, the efficient utilization of the fishery will necessitate measurements of the effects of these environmental fluctuations. In short, we need better and more accurate measures of the magnitude of the stock of fish and better understanding of the effects of both fishing and environment.

Beyond this, we need to understand the effects of fishing, not alone on the species fished, but on the associated species. The reduction in the numbers of a species must impose adjustments on its prey, its competitors, and its predators, thereby altering its own habitat favorably or otherwise.

Given an understanding of the effects of fluctuations in the abundance of some members of a biotic community on the abundance of others, we need capture methods of sufficient scope to make it feasible to manipulate the abundance of these members in a pattern that will maximize the abundance of the more valuable ones.

Granting the possession of fishing methods of the requisite scope, the establishment of high yield characteristics by selective breeding of the desirable species may provide a further means of increasing productivity.

And possibly, by means I hesitate to suggest, we may manipulate the weather and the sea, which could have enormous biological consequences through changes in the atmospheric and marine climate.

These hypothetical stages are given in Table 2.

We have reached stage two for some fisheries, but many are yet in stage one. Whether or not the remaining stages are reached will depend upon the need for food so pressing that even the restless sea must be tamed and its productivity directed towards that end.

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TABLE 2

STAGES IN THE DEVELOPMENT OF OPEN SEA FISHERIES

Stage	*Condition of Fishery*	*Method of Maximizing Yield*
1	Catch insufficient to reduce recruitment. Immature fishery.	Development of markets. Development of more efficient capture methods.
2	Catch sufficient to reduce recruitment. Mature fishery.	Regulate magnitude of catch.
3	Catch increased by increase in recruitment and survival.	Manipulation of fishing effort to alter relative species composition of the biotic community.
4	Catch increased through development of high yield varieties.	Manipulation of the genetic constitution of the stock.
5	Catch increased through improved physical environment.	Manipulation of the physical environment.

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THE INTRODUCTION OF AQUATIC ANIMALS INTO HAWAIIAN WATERS

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1. INTRODUCTION

The Hawaiian Islands, an isolated oceanic archipelago. have long been of interest to ecologists. The history of the group, since its discovery by Europeans and before, has been a history of successive invasions by new plants and animals and peoples. These invasions were superimposed on an indigenous flora and fauna and rapidly and irreversably altered it. The process of alteration has not been really understood or described. The present account of Hawaiian aquatic introductions is not an analysis of ecological alterations of the fauna of Hawaiian waters. It is rather an attempt to simply record such introductions and additions that have occurred insofar as available documentation permits and to describe, in general, the Hawaiian environment. Many of the less conspicuous aquatic invertebrates which have been fortuitously introduced are not listed. Like insect immigrants, they will quietly continue to establish themselves. Their recognition as immigrants often depends on their ultimate collection and proper identification.

2. REASONS FOR THE INTRODUCTION OF AQUATIC ANIMALS

While the introduction of some of the exotic aquarium fishes, such as *Limia vittata* may well be fortuitous, the majority of the aquatic animals listed here, 54 out of a total of 61, were deliberately introduced. Some of the remaining species may also have been purposefully released, but their establishment is considered fortuitous in the absence of any record.

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[1]) Published by permission of Director, Bureau of Commercial Fisheries.

The motives for making purposeful releases of aquatic animals are, of course, various, but can be conveniently grouped under the following categories: (1) Pest Control. The general establishment of mosquito fish and the stocking of some species of *Tilapia* in weed-filled irrigation systems were for this purpose. (2) Recreational and subsistence fishing. The introduction of game fish and *Tilapia*, too, were motivated by a desire to improve Hawaiian waters for such fishing. (3) Increased yield from fisheries. Many of the introductions made, were, of course, motivated by this hope. Some, such as the introductions of oysters and clams, bait fish species, and some species of reef fishes, were done largely for this reason. (4) The addition of familiar or ornamental fishes to the fauna. Perhaps many of the unrecorded introductions are of this kind.

This paper constitutes an expansion of my paper of 1952 (BROCK 1952). Much of the additional data regarding introductions since that date are from the records of the Hawaiian Division of Fish and Game.

3. DESCRIPTION OF THE HAWAIIAN AQUATIC HABITATS

The Hawaiian archipelago reaches, in a shallow crescent, 2,575 kilometers across the Pacific basin, between latitude 18° 55′ N. and longitude 154° 50′ W. to latitude 28° 25′ N. and longitude 178° 25′ W. This group of islands is ordinarily divided into two parts: the leeward or Low Islands, and the windward or High Islands. The eight High Islands have a total area of 16,667 square kilometers. The area of the ten Low Islands is about 16 square kilometers, but with shoal water areas (depths less than 200 meters) exceeding those of the High Islands.

This arc of islands, trending from Hawaii northwesterly to Kure, arise abruptly from the sea floor as an enormous dike of basaltic lava. The Leeward Islands are greatly eroded and are mantled by coral reefs. The Windward Islands are mountainous peaks 900 to 4,000 meters high and have narrow coral reefs or merely a thin cover of coral on the upper margin of steep submerged slopes.

The lavas of these islands are of various ages and have been, through differences in age and amounts of rain, subject to weathering and erosion in varying degrees. Those areas of most recent lava flows lack any permanent streams, as, for example, the Kona and Kau coasts of Hawaii, which are some 320 km. in length and fall along the base of Mauna Kea, Hualalai, and Mauna Loa. The new lavas of these areas are so porous that rain percolates through, forming a freshwater lens which seeps back into the sea along the shoreline. The windward sides of all the larger islands have streams, but only Kauai and Oahu have permanent streams on the leeward sides. In general, the windward streams tend to enter the sea abruptly with little or no brackish water areas at the mouth, while the leeward streams usually end in an estuary. The Hawaiian streams are subject to heavy freshets and are commonly torrential in their upper portions. Rainfall is occasionally very heavy, exceeding 50 cm. in 24 hours. This results in scouring of the stream beds.

Water temperatures in the streams are cool, considering the latitude of the islands. The important reasons for this are the rapid rate of drop in the streams from the headwaters to the sea and the shade afforded by dense vegetation overhanging the course of the streams. In general, air temperatures fall about 1° C. for each 165 meters of elevation and the water temperatures of a stream, by reason of flow from higher to lower elevations, tend to reflect temperatures for the higher elevations. The lower portions of a stream may range from 20° to 25° C., usually closer to 20° C. Streams in the Kokee area of Kauai, which sustain

Page	Correction
474	Under *Cephalopholis argus*, in line 5 of the paragraph, insert the word "of" between "summer" and "1958."
	Under *Cephalopholis argus*, in line 6 of the paragraph, replace "where" with "when."
475	Under *Lutjanus vaigiensis*, in the second line of the paragraph, change "Coconut Islands" to "Coconut Island" and change the "I" before "1956" to "In".
476	Under *Tevela stultorum*, capitalize "Pismo."
	Insert a second "s" in "*tschawytscha*."
477	Under "Discussion," in the second line of the third paragraph, a hyphen at the end of the line should indicate continuation of the word "introductions."
478	Correct spellings of "*Oncorhynchus tschawytscha*" and "*Xiphophorus helleri*."
479	In the first line of the first paragraph, "introduction" should be made plural.
	In the sixth line of the first paragraph, "conductive" should read "conducive."
	In the third line of the second paragraph, insert a comma after "irrigation reservoirs."
480	First line, correct spelling of "Pelekuna" to "Pelekunu."
	In the fourth line, insert "in" before "areas."
	In the second item of the Literature Cited, correct transposed letters in the name "George Vanderbilt." In the final item change "Hawallon" to "Hawaiian."

Int. Revue ges. Hydrobiol. 45(4):463-480, 1960.

The introduction of aquatic animals into Hawaiian waters by Vernon E. Brock

Page	Correction
463	In line [illegible] of the first paragraph, "irreversibly" is misspelled "irreversably."
	In line [illegible] of the first paragraph, "that" should be replaced with "as".
	In line 2 of the second paragraph, a comma should be inserted after "vittata".
464	In the second paragraph, line 2, replace "between" with "from."
	In the third paragraph, first line, "arise" should read "arises."
	In the third paragraph, line 3, a hyphen at the end of the line should indicate continuation of the word "mountainous."
467	Under Cytherea meretrix, in the last line of the paragraph, "Oaha" should be corrected to "Oahu."
	Under Crassostrea virginica, in line 6 of the paragraph, there should be a space after "Oahu."
468	In the fifth line on the page, "Astacus" should read "Pacifastacus."
	Under Scylla serrata, in line 6, replace "was" with "were."
469	Under Carassius auratus, in the second sentence, change "has" to "have."
	Under Misgurnus anguillicaudatus, in the second line of the paragraph, replace the semi-colon with a comma.
470	The word helleri should be spelled with one i.
472	Under Tilapia macrochir, second line of the paragraph, there should be a space after "by".
	Under Tilapia zillii, line 1, "B.E.I." should read "B.W.I."
473	The side headings "Mollusks:" and "Fish:" should be separated by a space of two lines from the paragraphs which precede them.

a breeding rainbow trout population, have temperature ranges between 10 C. to 18° C. depending upon season and degree of shade over the stream. This area is about 900 to 1,200 meters in elevation.

In addition to stream habitats, the irrigation systems, especially of the sugar plantations, supply an important habitat for aquatic animals. In general, the water in the irrigation systems is stored in reservoirs and distributed to the sugar cane fields by ditches or pipes. It is obtained, for the most part, by stream diversions, occasionally from wells. Water temperatures are usually somewhat higher in irrigation systems than in streams by reason of periods of storage in open sun. The reservoirs constitute the bulk of the pond fish habitat available.

Some estuarine habitat is present at the mouths of some streams and in harbors such as Pearl Harbor, Honolulu Harbor, Port Allen, and Hilo.

The Hawaiian marine habitats can be conveniently grouped into three categories: (1) sublittoral or reef, (2) pelagic and (3) benthic. These categories have been characterized in some detail by Gosline and Brock (1960). The introduced species, where purely marine, have been, with one exception, species of the sublittoral region. This region may be defined as that between the surf line and a depth of 50 meters. It includes some coral reefs, rocky and sandy areas, and admixtures of these. The water is clear and the fish fauna of the sort associated with coral reefs. Water temperature, where not locally modified by cooler fresh water escaping into the sea, has a seasonal range from 23° C. to 26° C.

The pelagic region is that of the open sea, and the benthic the sea floor between 50 and 250 meters.

These categories are admittedly artificial to a degree, but do contain distinctive assemblages of species.

4. NATURE OF THE ENDEMIC HAWAIIAN AQUATIC FAUNA

The Hawaiian archipelago constitutes one of the most isolated island archipelagos in the world. The nearest island is Johnston Island, which lies some 1390 kilometers to the southwest and is itself quite isolated. Beginning at approximately 1760 kilometers due south are the Line Islands. The nearest continental land mass is that of North America, which is some 3890 kilometers to the northeast. However, the Hawaiian fauna is clearly of Indo-Pacific origin. Considering the pattern of ocean currents, the origin of the fauna may be primarily from the coasts of tropical Asia which are bathed by the Kuroshio Current System. (Gosline and Brock, 1960.) During the winter months the island chain is usually surrounded by western Pacific water, part of a great eddy of which the Kuroshio constitutes the western and northern boundaries. Because of distance many of the species found in the western Pacific have not apparently been able to reach Hawaii. In some respects the effect of distance on the ability of various species of fishes to reach new areas may be akin to a filter. Those species whose life history patterns permit some sojourn in a pelagic environment have an innate advantage and can thereby traverse reaches of open ocean denied to other species not adaptable at any stage of their life history to the pelagic environment. Because of this, or possibly because of other reasons, the Hawaiian fauna, while clearly derived from the fauna of the western tropical Pacific, is lacking in a number of important elements of that fauna. It is, in a sense, an incomplete fauna, insofar as the inshore and freshwater species are concerned.

The character of the differences between the Hawaiian freshwater and marine fish fauna and that of other portions of the Indo-Pacific faunal region can be illustrated by an examination of the species composition of some groups of inshore and freshwater fishes. For the inshore fishes, the catalogue of FOWLER (1938) of the fishes of Eastern Oceania which included, besides the Hawaiian Islands, the Society Islands, the Marquesas Islands, and the Line Islands, is of interest. Among the sea basses or groupers, genera *Cephalapholis* and *Serranus* (= *Epinephelus*), Hawaii is credited with five species by FOWLER (of which only two really occur there, *Epinephelus quernus* Seale and *E. taurina* [FORSKAL]), while the remainder of Eastern Oceania has some 22 species belonging to these two genera. For the important genera of tropical snappers *Lutjanus* and *Letherinus*, FOWLER lists 16 species for Eastern Oceania exclusive of Hawaii, which has none. *Lutjanus* is, of course, found not only in the Indo-Pacific faunal region, but in the tropical Atlantic. Hawaii has only two species of sardine-like fishes while the remaining island groups of Eastern Oceania have eight.

If other genera or families of marine inshore fishes are considered, the Hawaiian fauna does not seem so depauperate. FOWLER lists 27 butterfly fishes (Family Chaetodontidae) for Hawaii and 29 for the remainder of Eastern Oceania; 21 surgeon fishes (Family Acanthuridae) for Hawaii and 26 for the remaining area. While, as indicated for the sea basses, these lists may not be exact, they do illustrate that Indo-Pacific fish genera tend to be either incompletely represented in Hawai, if not absent, or to be represented rather well.

A consideration of the life history of a representative of one of the families with a large number of Hawaiian species may be illuminating in this context. The Hawaiian manini (*Acanthurus triostegus sandirichensis*) has a pelagic larval stage persisting for $2\frac{1}{2}$ months (RANDALL, 1956) and in general this situation seems to be true for other acanthurids. The chaetodontids, mullids, and priacanthids, among others, also seem to pass through a pelagic stage early in their life history. Perhaps this feature can be considered as a dispersal mechanism, making it possible for such fishes to survive in the pelagic environment long enough to reach isolated islands.

There are no primary freshwater Hawaiian fishes. The endemic species are gobies which live entirely in fresh water as adults, or euryhaline species, such as *Kuhlia* or *Mugil*. The life history pattern of one of these gobies, *Chonophorus stamineus* (EYDOUX and SOULEYET), has been studied and is of interest in considering how it became a part of the Hawaiian fauna. The adults, which live high in mountain streams, migrate seaward during the period from mid-summer through early fall to spawn. The migration ordinarily coincides with a modest freshet which fills the stream. At the last rapids above the sea, the fish attach their eggs to boulders in the rush of the current. After hatching, the larval gobies are flushed downstream into the sea, where they spend some 6 months before returning to the streams. The larvae, migrating back from salt water, often enter the streams in large numbers. Here again, the period of larval existence in the sea may also be considered as a dispersal mechanism.

5. INTRODUCED SPECIES

The lack of primary freshwater fishes and the relatively depauperate situation obtaining for some large genera of inshore marine fishes may suggest the possibility of favorable environmental niches for some species not naturally found in Hawaii. While not examined by me, a parallel situation for the inshore and freshwater invertebrates may be anticipated. Some of the introductions were motivated by an appreciation of this situation. (See part 3 of table 1.)

The following list of introduced aquatic animals is incomplete. There has been no attempt to catalogue the fortuitous introductions of smaller invertebrates. Exotic aquarium fishes are imported in substantial numbers and in all likelihood some of these fish have become established, but their establishment has not yet been recognized and recorded.

a) *List of Established Introduced Species*

Mollusks:

1. *Venerupis philippinarum* (Adam and Reeve)

Common name: Japanese clam.

First recorded introduction in 1920 of some 10 barrels. The clams were brought from Japan and planted in Pearl Harbor, Kaneohe and Waialae Bay on Oahu. However, this species was reported to have been established on Molokai before 1920. It is presently well established on Oahu, Molokai and Hawaii, and possibly on Maui and Kauai.

2. *Cytherea meretrix* Linnaeus

Common name: Japanese clam.

The first shipment consisting of some 10 gallons of clams was brought in from Japan in 1926. These were planted in Kaneohe Bay and off Kalihi, Oahu. In 1939 a second shipment of 20,000 small seed clams was received from Japan and planted in Kaneohe Bay and Mokapu, Oahu. This species is well established on Oaha and possibly on other islands also.

3. *Crassostrea virginica* (Gmelin)

Common name: Eastern or Chesapeake oyster.

The valuable oyster of eastern North America was first reported to have been imported in 1871; however, the importation was apparently not successful. A shipment of 300 was brought in from San Francisco in 1883 and planted off Kalihi, Oahu. This planting also failed to establish this species. In 1893, 1,000 were brought in from San Francisco and 38,614 in 1895. Both of these shipments were planted at Manana, Ewa, in Pearl Harbor on Oahuand resulted in establishing the species in Pearl Harbor. While there were subsequent shipments they did not apparently contribute to its establishment in Hawaii. In recent years oysters taken from Pearl Harbor have been planted at localities on Kauai, Molokai, Maui, and Hawaii. Although there has been some evidence of successful spawning through the appearance of spat, these plantings are too recent to afford a basis for judging their success.

Crustacea:

4. *Procambarus clarkii* (Girard)

Common name: Crayfish.

The occurrence of this species in Hawaii is the result of erroneous identification. Another crayfish, *Pacifastacus leniusculus* (Dana), was reported as being introduced from California in 1923 and again in 1927. In 1937 and 1939 a total of 3,225 crayfish were distributed to various localities on Hawai and Kauai. The crayfish were taken from a taro patch at Ahumanu, Oahu, where they had been earlier established.

The species introduced at Ahumanu was reported to be *Pacifastacus nigrescens* (STIMPSON). However, the only species of crayfish currently found in Hawaii is the Louisiana crayfish, *Procambarus clarkii*. So far as the records show crayfish were brought in from either California or possibly Oregon, and it is likely that the introduced *Procambarus* was collected rather than the native *Astacus*. Presently the Louisiana crayfish is abundant on all the major islands and is considered a pest in taro patches from its habit of burrowing through dikes allowing the escape of water used to irrigate the taro.

5. *Scylla serrata* (FORSKAL)

Common name: Samoan Crab.

This large crab has a wide distribution from Africa and India through tropical Asia and Polynesia. The normal habitat is saltwater swamps and mangrove areas. Beginning in 1926 a few crabs were brought in each year from Samoa until by 1935, the last year of any introductions, a total of 98 crabs had been released in Hawaiian waters. The largest number brought in during a single year was 23 (introduced in 1932) and aside from the introductions during 1932, which was on the Hilo coast of Hawaii, all the introductions were at various localities on the island of Oahu. Today this crab is common in the waters of all the major islands of Hawaii. It is valued as food and brings a good price in the local markets.

Fish:

6. *Harengula vittata* (CUVIER & VALENCIENNES)

Common name: Marquesan sardine.

The Marquesan sardine is the first species of a purely marine fish established in Hawaiian waters by transplantation. An account of the introduction of this species is given by MURPHY (1960). The initial introduction from the Marquesas Islands was made in December of 1955 when some 7,500 fish were released off Barbers Point, Oahu. There was a single introduction of 7,900 fish in the fall of 1956 and two large lots of 24,000 and 32,000 in March and December of 1957. A large introduction of 56,000 was made in February of 1958, followed by two smaller plantings of 9,400 and 3,000 in May and June. The last planting of 4,000 was made in March of 1959. All releases of this species were made at various localities around the island of Oahu.

Although as early as the fall of 1956 recoveries of small numbers of Marquesan sardines were made, beginning in the late summer of 1958, some of the fish recovered were too small in size to be derived from any of the original introductions. Additionally, up to this time, all recoveries were from Oahu; many of these later recoveries of small fish were from Kauai, Maui and Hawaii. The large plantings made in 1957 and early in 1958 may have provided a sufficient stock of fish to establish the species. The recoveries which could be attributed to the small plantings of 1955 and 1956 were few and of such a size to suggest that they were all a portion of the original releases.

7. *Dorosoma petenense* (GUNTHER)

Common name: Threadfin shad.

The threadfin shad was first introduced in 1958. A small stock secured from the Chino Fish Station of the California Department of Fish and Game was flown to Hawaii and released in a hatchery pond at Nuuanu, Oahu. Subsequently some

53 of these fish were released in the quarry pond on the campus of the University of Hawaii.

Following this introduction, a large number of fish were brought to Hawaii from the Puddingstone Reservoir near Chino, California; however, these fish were used in sea tests of this species as livebait for tuna fishing. Another large introduction of some 3,000 fish was again made in August, 1959, from Puddingstone Reservoir and these fish were released in various localities on Kauai, Oahu, and Maui.

8. *Salmo gairdneri* RICHARDSON

Common name: Rainbow trout.

This species has been repeatedly introduced to all islands. From 1920 to 1959 about 270,000 trout fry, hatched from eyed eggs brought in from California, Oregon and Washington, have been released in various island streams. While a permanent breeding population of rainbow trout occurs in the streams of the Kokee area of Kauai, the needs of the sport fisheries cannot be met by the reproductive rate of the Kokee fish, and it is therefore supplemented by stocking from imported eggs.

9. *Cyprinus carpio* LINNAEUS

Common name: Carp

The carp was introduced prior to 1900 and is found today on all major islands, generally in impoundments.

10. *Carassius auratus* (LINNAEUS)

Common name: Goldfish

This species was established here before 1900 and occurs on all major islands. There has doubtless been many reintroductions.

11. *Barbus semifasciolatus* GUNTHER

Common name: Half-banded barb

This species is an exotic aquarium fish which was released in Nuuanu Reservoir 3 on Oahu. It can be considered as established in Hawaii, but its establishment is precarious as the drainage of the reservoir would probably remove it from the Hawaiian fauna.

12. *Misgurnus anguillicaudatus* (CANTOR)

Common name: Dojo

The dojo was established on Kauai, Oahu and Maui before 1900. It is found in many localities on those islands; its use as bait for fishing being apparently instrumental in its spread.

13. *Clarias fuscus* (LACEPEDE)

Common name: Oopu kui

The Asiatic catfish was established in the waters of Kauai, Oahu, and Maui prior to 1900. It is a common fish.

14. *Gambusia affinis* (BAIRD and GIRARD)

Common name: Mosquito fish

This, and several other species, were brought to Hawaii from Seabrook, Texas, in 1905 for mosquito control. An account is given of the introduction of *G. affinis*, *Mollienesia latipinna* and *Fundulus grandis* by VAN DINE (1907). The initial stocking was at Moanalua, Oahu, and young fish from this locality were subsequently introduced into the fresh waters of all the islands. This species is most abundant in the lower portions of streams, while *Lebistes reticulatus* is abundant in the middle reaches.

15. *Mollienesia latipinna* LE SUEUR

Common name: Sailfin

The sailfin was introduced in 1905 from Seabrook, Texas, and established initially at Moanalua, Oahu. A second introduction was made in 1940 to the Nuuanu Reservoir on Oahu; this stock was largely of the black cultivated variety. In 1950, 21 pounds of sailfins were taken from Kapalama Canal, Oahu, to Port Allen and Nawiliwili, Kauai, but apparently did not survive. The Seabrook, Texas, stock is well established in brackish water areas of Oahu and Molokai.

16. *Limia vittata* (GUICHENOT)

Common name: Top minnow

Limia vittata is found in the streams flowing through Honolulu which include Moanalua, Kapalama Canal, Nuuanu, and Manoa streams. It is found in the lower portions of the streams and in salt water. The origin and date of introduction are not known.

17. *Lebistes reticulatus* (PETERS)

Common name: Guppy

The guppy was introduced in 1922 and established in streams flowing through Honolulu and into Kaneohe Bay as well as some others on the windward side of Oahu.

18. *Xiphophorus maculatus* GUNTHER

Common name: Moonfish

This species was introduced in 1922 on Oahu and again in 1940 in the Nuuanu Reservoir, Oahu. The species has been taken in some irrigation reservoirs on Maui; the date and manner of introduction of the fish there are not known.

19. *Xiphophorus hellerii* HECKEL

Common name: Swordtail

First introduced into the streams around Honolulu and Kaneohe Bay, Oahu, in 1922. Nuuanu Reservoir was stocked in 1940 and many of the leeward streams on Kauai were stocked, but with, in some instances, the red hybrid swordtail type. The dates of these plants are not known.

20. *Micropterus salmoides* (LACEPEDE)

Common name: Largemouth bass

Largemouth bass were first brought to Hawaii in 1897 from California. Only 21 fish survived the trip to Hilo, where they were released in the Wailuku River which flows through that city. This species does not occur today in the Wailuku River, but is well established in the Waiakea mill pond in Hilo, which is spring fed, and in the large stream flowing from it. A shipment from California to Oahu in 1908 was released in the Wahiawa reservoir which established the species there. In 1911 some 300 largemouth bass were brought to Kauai from California and released in Waiuli reservoir and Koloko reservoir. The species is well established today on all major islands.

21. *Micropterus dolomieu* LACEPEDE

Common name: Smallmouth bass

Seventy-four smallmouth bass were initially brought from Elk Grove Hatchery in California to Oahu in 1953. For a time these fish were at the Fish and Game Laboratory in Honolulu, and subsequently the survivors were released in a lily pond near the Nuuanu Reservoir where they spawned. Some of the original stock, together with offspring, were released in Nuuanu Reservoir and by 1956 were well established there. In May of that year a shipment of 1200 small fish were received from the Elk Grove Hatchery of the California Department of Fish and Game. Beginning in 1956 smallmouth bass were planted in both forks of the Waialua River on Kauai, in Kaukonahua Stream above Wahiawa Reservoir on Oahu and, by 1958, in Puakea Reservoir on Hawaii. The bulk of the stock for these plants came from Nuuanu Reservoir with some additions from the large 1956 shipment. The species is established on Kauai and Oahu and possibly on Hawaii.

22. *Lepomis macrochirus* RAFINESQUE

Common name: Bluegill

Fourteen fish were brought from California in 1946 and established in a private lily pond near Kaneohe Bay, Oahu. The bluegills reproduced in this pond and young were thereafter stocked in suitable places on all major islands. This species is well established in the Hawaiian Islands.

23. *Cichlasoma meeki* (BRIND)

Common name: Firemouth

Established in Nuuanu Reservoir by a release in 1940. Reported to occur also in a drainage canal in the McCully district of Honolulu.

24. *Astronotus ocellatus* (AGASSIZ)

Common name: Oscar

A small stock of this species was obtained from the Steinhart Aquarium in San Francisco and was successfully bred in tanks at the Fish and Game Laboratory. Sixty-four young, a portion of a brood, were released in Nuuanu Reservoir 2. Subsequently young fish, offspring of some of the 64 originally introduced, were taken from this reservoir and stocked in Wahiawa Reservoir on Oahu and Waialua Reservoir on Kauai. These last plants are too recent (1958) to judge their success.

25. *Tilapia mossambica* (PETERS)

Common name: Tilapia

In 1951 some 60 small *Tilapia* were sent to Honolulu from Singapore. Of the original shipment, all but 14 subsequently became diseased and died. The 14 survivors bred in the laboratory tanks of the Fish and Game Division and the resultant offspring were used for stocking purposes. This species has been useful for four purposes in Hawaii: (1) as live bait for tuna fishing; (2) as a means of controlling certain aquatic plants in irrigation systems; (3) as a food fish — modest quantities are sold in local markets; and (4) for sport fishing — tilapia provides good fishing especially for youngsters. It is well established on all of the major Hawaiian Islands.

26. *Tilapia macrochir* (BOULENGER)

Common name: Tilapia

Tilapia macrochir was first introduced in 1957, from Leopoldville, Belgian Congo, bya shipment of 52 fish 4 to 5 centimeters in length. Beginning in 1958 this species was stocked out, using offspring obtained from the original stock in the Fish and Game Laboratory tanks, in Wahiawa Reservoir. Additional plantings were made in Wahiawa Reservoir in 1959 until a total of 1,279 fish, 5 to 8 centimeters long, were released. During 1959, 150 fish were also released on Maui.

27. *Tilapia zillii* GERVAIS

Common name: Tilapia

A shipment of *T. zillii*, numbering 19 fish, was received from Antigua, B. E. I. in 1955. These fish were held and bred in the Fish and Game Laboratory tanks until 1957 when 1,500 fish were released in plantation reservoirs on Maui. Plantings were made in 1958 and 1959 in reservoirs on Hawaii and Oahu. *Tilapia zillii*, where stocked in a weed-filled reservoir, has done, in some instances, a remarkable job of removing aquatic vegetation. Often where some domestic use is made of the water, chemical methods of control are not practical and in any case these methods must be continuous.

28. *Tilapia melanopleura* DUMERIL

Common name: Tilapia

Tilapia melanopleura was obtained from Leopoldville, Belgian Congo, in 1956 in a single shipment of 50 fish. After breeding fish in the Fish and Game Laboratory tanks, releases of young were made on Kauai in 1957 and 1958. A total of 1,673 fish were released in a drainage canal and reservoir at Kekaha, Kauai. These introductions were made for the purpose of controlling aquatic vegetation too coarse for *T. mossambica*.

29. *Ophiocephalus striatus* BLOCH

Common name: Snakehead

The snakehead is another species of oriental origin that was established on Oahu prior to 1900. It is not uncommon.

30. *Fluta alba* (ZUIEW)

Common name: Ricefield eel

The ricefield eel was established on Oahu before 1900. It is common but secretive, and is occasionally dug out of old taro fields alive long after the field has been drained.

b) *Supplemental List 1,*
Species That May Be Established

Many of the species listed here can be taken or seen in a wild state; however, their introduction is recent and there is no clear-cut evidence of successful repro-

duction and the ocurrence of young. It is likely that some of the species in this list will become established and others will not.
Mollusks:

1. *Haliotis cracherodii* Leach

Common name: Black abalone

The first introduction of this species, which has a more southerly range than the other abalones of California, was in 1927 and 1928 when a total of 35 was brought in from California. Some of these may have been the red abalone *Haliotis rufescens*. There was no evidence of survival.

In 1958, 167 black abalones from California were planted off Rabbit Island, Oahu. There was some evidence of poaching found when later checking on the success of this planting. In August of 1959 and again in September of that year a total of 728 black abalones were planted off Pyramid Rock, Oahu. In a check of the first Pyramid Rock planting subsequently, some 19 abalones were found moribund and some 20 apparently in excellent shape. The survivors seemed to be those which were able to find adequate shelter. These were small abalones 2.5 to 7.5 centimeters in shell diameter and were from southern or Lower California.

Crustacea:

2. *Macrobrachium lar* (Fabricius)

Common name: Giant freshwater shrimp

Some 340 shrimp were brought to Honolulu from Guam in 1956. Shortly after, 94 were released in Pelekunu Stream on windward Molokai and the remainder held in the Nuuanu hatchery pond of the Fish and Game Division. In 1957, some 27 shrimp were released in Nuuanu Stream on Oahu. Some of the remaining shrimp held at the hatchery spawned and the eggs hatched but there was no evidence of survival of young. It is possible that the larvae of this species require a sojourn in salt water.
Fish:

3. *Ictalurus punctatus* (Rafinesque)

Common name: Channel catfish

The channel catfish was first introduced in 1953 and again in 1954 from California. A total of 38 fish were received and were held for 5 years at the Nuuanu hatchery in an attempt to propagate the species. This attempt was not successful and some of the mature fish were lost through the use of hormone injections to induce spawning. In 1958, 1,715 young, brought in from Fort Worth, Texas, were released in Wahiawa Reservoir, Oahu. Another planting of 4,500 was made in Wahiawa Reservoir in 1959 as well as one of 1,300 in the Waialua River on Kauai. These fish were shipped in from a hatchery in Oklahama. A few catfish have been taken in Wahiawa Reservoir indicating both survival of the original planting and excellent growth of the fish.

4. *Kuhlia rupestris* (Lacepede)

Common name: Nato

A shipment of 43 *K. rupestris* was received from Guam in 1957 and held in Fish and Game Laboratory tanks. In 1958 another shipment of 170 was received and 104 of this shipment were subsequently planted in a small stream at Bellows Field, Oahu.

5. *Cephalopholis argus* (BLOCH and SCHNEIDER)

Common name: Roi

In 1956, 571 were brought to Hawaii from Moorea, Society Islands. These fish were given a prophylactic treatment of copper sulphate for 5 days and then planted in two lots: 171 off Browns Camp, Oahu, and 400 off Keahole Point, Hawaii. Underwater photographs of roi were obtained off Browns Camp in 80 feet of water during the summer 1958, and the Hawaii planting was investigated in the fall of 1958 where 11 fish were sighted, including a small one of 15 cm. which suggests that some reproduction had occurred. The fish deemed to be from the original plantings had evidently grown since no fish longer than 30 centimeters were brought to Hawaii while many of those sighted in 1958 were estimated to be 45 cm. or more in length.

6. *Cephalopholis urodelus* Bloch and SCHNEIDER)

Common name: Rero

Eight *C. urodelus* were released off Browns Camp, Oahu, in 1958. These fish were part of a shipment from the Marquesas Islands.

7. *Epinephelus merra* BLOCH

Common name: Tarao

Plantings of this species were made in 1956 at Wainini, Kauai, and Kaneohe Bay, Oahu, where 132 were released at the first-named locality and 469 at the second. The fish came from Moorea, Society Islands.

8. *Epinephelus spiniger* (GUNTHER)

Common name: Not known

Some 22 *E. spiniger*, brought from the Marquesas Islands in 1958, were released at Browns Camp, Oahu.

9. *Epinephelus fasciatus* (FORSKAL)

Common name: Matapuu

This species was brought from the Marquesas Islands in 1958, and 51 fish were released off Browns Camp, Oahu.

10. *Epinephelus hexagonatus* (BLOCH and SCHNEIDER)

Common name: Tarao a'au

Some 113 *E. hexagonatus* were released off Keoneoio, Maui, in 1956. The fish were brought from Moorea, Society Islands.

11. *Lutjanus gibbus* (FORSKAL)

Common name: Tuhara

L. gibbus was brought in from the Marquesas Islands in 1958, and released in Kaneohe Bay, Oahu. There were 40 fish in this release.

12. *Lutjanus kasmira* (FORSKAL)

Common name: Taape, Blue-lined snapper

Five *L. kasmira* were brought from the Marquesas Islands in 1955 and held in captivity at Coconut Island, Kaneohe Bay, Oahu. In 1958, 2,435 *L. kasmira* were released in Kaneohe Bay from a shipment originating in the Marquesas Islands.

13. *Lutjanus vaigiensis* (QUOY and GAIMARD)

Common name: Toau

The first shipment of 40 *L. vaigiensis* to Hawaii came from the Marquesas Islands in 1955. These fish were held captive at Coconut Islands. I 1956, 239 *L. vaigiensis* from Moorea, Society Islands were released in Kaneohe Bay, Oahu. In 1958, 23 additional *L. vaigiensis* from the Marquesas Islands were released in Kaneohe Bay.

14. *Lutjanus guttatus* (STEINDACHNER)

Common name: Spotted Rose Snapper

In May 1960, an estimated 3,000 spotted rose snappers were released in the lee of Ilio Point, Molokai, and 400 more in Kewalo Basin, Oahu. These snappers were collected off Manzanillo, Mexico, during the spring of 1960 and brought to Hawaii in the bait tanks of the M. V. CHARLES H. GILBERT, a research vessel of the Bureau of Commercial Fisheries, U. S. Fish and Wildlife Service.

c) *Supplemental List 2,*

Introduced Species Which Probably did not Survive

Mollusks:

1. *Ostrea lurida* CARPENTER

Common name: California oyster

This species was brought from San Francisco to Manana, Oahu, in 1893. There were some 3,000 oysters in the shipment.

2. *Crassostrea gigas* (THUNBERG)

Common name: Japanese oyster

A small shipment of unknown size from Japan was planted at Kalihi, Oahu, in 1926. Another shipment of 2,500 was planted at Pearl Harbor and Mokapu, Oahu, in 1938, and in 1939 a large shipment of seed oysters, some 2,150,000, were set out at Coconut Island and Mokapu in Kaneohe Bay, Oahu.

3. *Crassostrea amasa* (IREDALE)

Common name: Coral rock oyster

A sack of this species, 75 pounds in weight, was shipped from Australia in 1956. The oysters were established in Coconut Island ponds where they seemed to do quite well, and some were still living in 1959, but there was no evidence of reproduction.

4. *Crassostrea commercialis* (IREDALE and ROUGHLEY)

Common name: Australian oyster

There were two importations of this species, one of 3 bushels in 1928 and another of 24 bushels in 1929. The shipments were from Port Stephens, New South Wales, Australia and were planted at various localities on Oahu, including Mokapu.

5. *Pinctada martensii* (DUNKER)

Common name: Japanese pearl oyster

A small shipment was made in 1956 from Japan and placed in a holding area in the Kewalo Basin channel, Oahu.

6. *Tevela stultorum* (MAWE)

Common name: Pismo clam

Two shipments of 218 pismo clams were made in 1927 and 1928 from California. They were stocked out at Kahana and Kailua, Oahu.

7. *Tridacna crosea* LAMARCK

Common name: Giant clam

Sixty *T. crosea* were brought from Rose Island in 1951 and established in holding ponds at Coconut Island. A few of these clams were alive in 1959 but there was no evidence of reproduction.

Fish:

8. *Anchoa compressa* (GIRARD)

Common name: California anchovy

A release of 6,000 *A. compressa* was made in Kaneohe Bay, Oahu, in 1932. The fish were part of a load of live bait aboard a tuna clipper from California.

9. *Salmo trutta* LINNAEUS

Common name: Brown trout

This species was released in various localities on Kauai in 1935. Some 24,000 fry were planted from eggs presumably brought to Hawaii from one of the Pacific states. A large dead brown trout was found after a freshet in the Wainiha Stream on Kauai in 1949, indicating survival in that stream to that date, at least.

10. *Salvelinus fontinalis* (MITCHELL)

Common name: Brook trout

Three plantings of this species in Hawaii have been made. For the first, in 1876, from the California Fish Commission, we have no record concerning either the number or the places stocked. A second planting of 1,000 at Waimea, Kauai, was made in 1894, and a third of 12 fish at Wailuku, Hawaii in 1896. Fish for these last two plantings were also from the California Fish Commission.

11. *Plecoglossus altivelis* TEMMINCK and SCHLEGEL

Common name: Ayu

In 1925, 250,000 ayu were planted in various localities on Kauai, Oahu and Hawaii. The shipment came from Japan.

13. *Oncorhynchus tschawytcha* (WALBAUM)

Common name: King salmon

A shipment of unknown size of this species was made to Hawaii from the California Fish Commission in 1876. The release localities were not known. In 1925 and 1927, 66,000 king salmon fry were released on Kauai at various localities.

13. *Ictalurus nebulosus* (Le Sueur)

Common name: Brown bullhead

Reported to have been released near Hilo, Hawaii in 1893. The origin of the shipment and the number released is not known.

14. *Fundulus grandis* (Baird and Girard)

Common name: Killifish

An unknown number was brought from Seabrook, Texas in 1905 and released at Moanalua, Oahu.

15. *Oryzias latipes* (Schlegel)

Common name: Medaka

Reported to have been stocked in unknown numbers on Oahu in 1922.

16. *Roccus saxatilis* (Walbaum)

Common name: Striped bass

An unknown number of striped bass was brought to Hawaii from San Francisco Bay, California in 1922. Releases were made at a number of localities on Kauai.

17. *Trichogaster leeri* (Bleeker)

Common name: Pearl gorami

A few pearl gorami were released in Nuuanu Reservoir, Oahu in 1940. They have never been taken since.

18. *Osphronemus goramy* Lacepede

Common name: Giant gorami

In 1950, 9 small giant gorami were brought to Hawaii from the Philippines.Some of these survived for a long time, but did not reproduce. There may have been earlier unsuccessful introductions.

6. DISCUSSION

Listed in Table 1, by habitat, are the introduced species. This list is divided into three major parts: (1) established species, (2) species that did not become established, and (3) species introduced too recently to permit grouping in either of these two categories.

Of the species successfully established, one is a marine fish of open water, four are primarily estuarine, 19 are primarily pond dwelling and five are species found in streams. Of course, some of these species are found in more than a single habitat.

The introduction of species into the Hawaiian marine environment has been only attempted on a reasonable scale since 1956, and many of the marine introductions made since that date seem to be surviving but evidence of reproduction is lacking. It is not unlikely that the number of individuals introduced may be crucial in determining the success of establishing a new species, especially in a marine environment. The history of the establishment of the Marquesan sardine in Hawaii suggests that those releases of fish with 20,000 or more individuals were important in the establishment of this species while those of 10,000 or less were not.

Table 1

Species	Open Sea	Reef	Estuary	Pond	Stream
(1) Established Species					
Venerupus philippinarum			×		
Cytherea meretrix			×		
Crassostrea virginica			×		
Procambarus clarkii				×	×
Scylla serrata			×		
Harengula vittata	×		×		
Salmo gairdneri					×
Cyprinus carpio				×	
Carassius auratus				×	
Barbus semifasciolatus				×	
Misgurnus anguillicaudatus				×	×
Clarias fuscus				×	×
Gambusia affinis				×	×
Mollienesia latipinna			×	×	
Limia vittata			×	×	×
Lebistes reticulatus				×	×
Xiphophoruss maculatus				×	
Xiphophorus hellerii				×	×
Micropterus salmoides				×	×
Micropterus dolomieu				×	
Lepomis macrochirus				×	
Cichlasoma meeki				×	
Astronotus ocellatus				×	
Tilapia mossambica			×	×	
Tilapia macrochir				×	
Tilapia zillii				×	
Tilapia melanopleura				×	
Ophiocephalus striatus				×	
Fluta alba				×	
Did Not Establish					
Ostrea lurida			×		
Crassostrea gigas			×		
Crassostrea amasa		×			
Crassostrea commercialis			×		
Pinctada martensii			×		
Tivela stultorum		×			
Tridacna crosea		×			
Anchoa compressa	×		×		
Salmo trutta					×
Salvelinus fontinalis					×
Plecoglossus altivelis					×
Oncorhynchus tschawytcha	×				×
Ictalurus nebulosus				×	
Fundulus grandis				×	
Oryzias latipes				×	
Roccus saxatilis	×		×		
Trichogaster leeri				×	
Osphronemus goramy				×	

Table 1 — continued

Species	Open Sea	Reef	Estuary	Pond	Stream
Introduced Species That May Become Established					
Haliotis cracherodii					
Macrobrachium lar				×	
Ictalurus punctatus					
Kuhlia rupestris					
Cephalopholis argus		×			
Cephalopholis urodelus		×			
Epinephelus merra					
Epinephelus hexagonatus					
Epinephelus spiniger					
Epinephelus fasciatus					
Lutjanus gibbus					
Lutjanus kasmira					
Lutjanus vaigiensis		×			
Lutjanus guttatus		×			

[1]) Sand beaches.

The successful estuarine introduction were three mollusks and a crab. While not much can be concluded from the successful introduction of the mollusks — in contrast to those species which failed to become established — the success in establishing the Samoan crab in view of the few individuals introduced seems remarkable. However, some of the estuarine areas where this species was released have a low rate of tidal flushing, a situation which may be conductive to the rapid growth of a population within the estuarine area.

The pond habitat in Hawaii is essentially artificial, being primarily irrigation reservoirs. There are no indigenous species with ponds as a primary habitat. Since most reservoirs, especially irrigation reservoirs are drainable, this is a precarious habitat. Nevertheless, the pond habitat has the greatest number of successful introductions, some 19 in all. Some of the lower portions of the larger streams contain deep areas which are suitable for pond species that can also resist freshets which occasionally but inevitably occur. Both *Clarius fuscus* and *Misgurnus anguillicaudatus* are found in this habitat.

In general, Hawaiian streams are small, rapidly flowing brooks, torrential in their upper reaches. The native freshwater species of fish are dependent upon free access to the sea primarily to complete their reproductive cycle. In the development of some of the major irrigation systems, canals were channeled along the contours of the mountains at elevations above the highest sugar canefields and the stream water for each of the crossing streams diverted into the canal. Such diversions seriously reduced stream flows in the lower reaches especially during periods of low water and apparently reduced the population of gobies that normally reside in the upper parts of the stream but must descend to the lowest part to spawn. The invasion of exotic fishes, aside from trout, was, insofar as streams are concerned, primarily in the lower and middle reaches and here the possibility existed that the goby fry, migrating in from the sea, would be exposed to predation by those exotics. Of course, there are other predators, perhaps more serious, such as man, but in any case abundant stocks of native stream fishes are to be found in remote windward streams of great difficulty of access, and without irrigation diversions or populations of exotic fishes, such as Pelekuna Stream on Molokai.

Whether or not trout introductions had any major effect on native freshwater fish is difficult to evaluate, but areas where trout thrive, such as the Kokee area of Kauai, water temperatures are perhaps lower than that which is optimum for native stream fishes. Ordinarily, streams above elevations of 800 meters seem to lack native fishes.

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FISH SCHOOLING: A POSSIBLE FACTOR IN REDUCING PREDATION

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Fish Schooling:
A Possible Factor in Reducing Predation

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Introduction

The schooling of fishes has long attracted attention, and a number of workers have studied fish schools and the behaviour pattern of the fish to gain some understanding of the nature of the factors responsible for schooling.

PARR (1927) described the schooling behaviour of chub mackerel and killifishes in aquaria and concludes that the behaviour observed is a visual response to other individuals of the same species. BREDER and HALPERN (1946) found that blinded goldfish do not school, and BREDER (1951) in his study of schooling in *Jenkinsia* states that schooling will not occur in darkness or with blinded fish for some ten species which have been tested by various authors. KEENLEYSIDE (1955) found that blinded fish did not school effectively but there was evidence that the blinded fish could detect others, possibly through smell. SPRINGER (1957) concluded that his observations of a school of *Jenkinsia* "make untenable the view that individual fish of this school maintained contact with one another solely by visual means". BREDER (1954) developed equations descriptive of the forces in schooling.

In general, the concern of the authors briefly reviewed above was with the internal factors responsible for schooling, and the school was considered largely as an isolated phenomenon. However, BREDER and HALPERN briefly discuss the possibility that schooling may confer some protection from predation and indicate some of the difficulties which must be considered, but the matter is not developed quantitatively. SPRINGER described a school which resembled an unknown large creature as an example of "collective mimicry" and was, in the authors' opinion, protected by its frightening appearance. WELTY (1934) experimented with the effects of grouping fishes on learning, and found that, except for mudminnows, grouped fishes learned faster, retained longer, and ate more than did isolated fishes of the same species. The grouped fishes tended to respond as a unit, a mixture of fishes with two different responses to the same stimulus responded more slowly than did a group trained to give a single uniform response to the stimulus, an effect which WELTY labelled group cohesion.

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Species of fish that ordinarily school and school strongly seem to have two characteristics in common: (1) they are open water species whose immediate environment offers little in the way of shelter and (2) they are not climax predators, at the end of a food chain, but are prey species at least for a substantial portion of their life history. Likewise, the predators at the end of a food chain are ordinarily non-schooling, solitary fish.

This aspect of the predator-prey relationship suggests that schooling may confer some protection against predation and that for perhaps similar reasons predators function more effectively if solitary.

The schooling of some predatory species such as the tunas does not necessarily constitute contrary evidence. There is evidence that for much of the life span of these species, they are prey species, and when they do attain sizes sufficient to render them largely immune from predation, the schools formed are smaller and less stable than is true for younger and smaller fish of the same species. SETTE (1950) suggests that schooling of predators may assist in the capture of prey. His discussion of the reasons for such an advantage would seem to apply after the prey was located. If the relationships suggested in this paper between predator and prey be true, it would seem that schooling by a predator may, under some conditions, reduce the efficiency of scouting for prey.

If schooling does provide some protection against predation, this may occur simply because scattered prey will be detected more frequently by a predator than would be true of the same number of prey bunched into a school. While the true measure of the validity of this concept must depend upon observations and measurements in the field, certain relationships which seem essentially reasonable, make it seem likely that schooling is, in one common aspect, a mechanism of protection against predation. This aspect of schooling will be discussed with the assumption that the means of detection employed by the predator is visual. Other means of detecting prey are, of course, possible; their use would not change the conclusions reached on the basis of a visual model unless detection is independent of distance.

Consider schooling as a protective device; there are two factors operating at cross purposes: if a single fish is regarded as a group of size one, schooling (a) reduces the number of groups and consequently the frequency of encounter with predators; we shall call this encounter advantage; (b) increases the size of groups, thus increasing the chance of detection; we shall call the advantage here lost a detection advantage. A third factor which may give an advantage from schooling is the limitation of capacity of the predator. If a predator sights a large school of prey, he will eat to capacity, possibly leaving alive most of the school, and will reduce his searching activity to a negligible amount for some time thereafter. We shall call this advantage due to the predator's limited capacity a capacity advantage.

Development of Method

We shall develop probabilities for advantages of schooling on the basis of mathematical models relating to the above events. We shall consider in this paper only non-schooled predators; if predators school, they overlap each other's sight ranges, reducing the volume of ocean scouted and hence reducing scouting efficiency. Schooling of predators would be advantageous to the predators only in the special case in which their prey are schooled and cannot be seen at full sight range; here a predator could see another predator engaging in feeding activity when he could not see the prey being consumed. A consideration of the optical peculiarities of water is pertinent in this connexion. The distance which an object of given size can be seen depends upon two factors: the intercept angle at the eye and the contrast difference between the object and the background. Due to backscatter and light absorption an object of the highest contrast will fade from sight regardless of size at a relatively small distance, say 200 feet or less, even in the clearest water. This means that for objects above a fairly modest size, large enough to give an intercept angle adequate for effective vision at the distance where light absorption and backscatter reduce contrast difference to the point of invisibility, taken at 2 per cent. for man (DUNTLEY, 1952), any increase in the size of the object will not effectively increase the distance which it may be seen. The critical intercept angle for the human eye is taken as one minute which would occur for an object 0·72 inches in diameter at 200 feet.

Consequently the observation of feeding behaviour of a predator by another as a means of locating food would be effective only for rather small prey: the greater the reduction of sight range by contrast loss, the smaller the prey.

In supposing that schooling is of advantage to prey, we shall give predators every advantage, hence the first two assumptions given below. But predation will be assumed effective only during daylight hours.

Definitions:

(1) n_p represents the number of predators.
(2) n_f represents the number of prey (f for food fish).
(3) n_e represents the number of schooled prey a predator can hold at one eating.
(4) r represents the distance at which a predator can see its prey.
(5) r' represents the radius of a school of prey (assumed to be approximately spherical).
(6) d_{ik} represents the distance between the ith prey and the kth predator, $i = 1, 2, \ldots, n_f$, $k = 1, 2, \ldots, n_p$.
(7) $d_{k'}$, represents the smallest d_{ik} for any k, i. e. $\min(d_{ik})$, $k = 1, 2, \ldots, n_p$.

Assumptions:

(8) If a predator is in sight of a prey, he will sight it.
(9) If a predator sights a single prey, he will eat it.
(10) The average distance between predators and between non-schooled prey is greater than r.
(11) Predators and prey move randomly.
(12) The concentrations of predators and prey are constant.
(13) If schooling occurs, all members are schooled and schooled in a single school. (It will be seen later that this assumption may be relaxed.)

d_{ik} are random continous variables, and therefore so are $d_{k'}$. Whenever $d_{ik} > r$, the ith prey remains alive; thus whenever $d_{ik} < r$, the ith prey is eaten. Let us denote by $P[d_{ik} \leq r]$ the probability that the ith prey is sighted (and therefore eaten) by the kth predator.

Since the d_{ik} are random for all i and all k and the initial positions of all fish at daybreak are random,

(14) $P[d_{ik} \leq r] = P[d_{jl} \leq r],\ i, j = 1, 2, \ldots, n_f;\ k, l = 1, 2, \ldots, n_p.$

Hence the expected number of non-schooled forage fish which will be eaten is $n_f n_p P[d_{ik} \leq r] = E_1$.

In the case of schooled fish, the probability that the kth predator will sight the school will be $P[d_{k'} \leq r]$, $k = 1, 2, \ldots, n_p$. Since d_{ik} are random for all k and inital positions of predators at daybreak are random,

(15) $P[d_{k'} \leq r] = P[d_{l'} \leq r],\ k, l = 1, 2, \ldots, n_p.$

Hence the expected number of schooled prey which will be eaten is $n_e n_p P[d_{k'} \leq r] = E_2$.

It follows that whenever schooling is advantageous to the prey,

$$E_2 < E_1, \tag{16}$$

or, upon substituting, rearranging, and cancelling,

$$\frac{n_e}{n_f} < \frac{P[d_{ik} \leq r]}{P[d_{k'} \leq r]} \tag{17}$$

since all components are non-negative.

At this point a few comments are in order. It should be clearly recognized that the primary variable (d_{ik}) being considered is distance and is the distance between two particular, randomly placed fish; it does not involve a number of fish in any sense. It would be possible to consider the number of prey within sight of the predator at any time, which would be a discrete variable having a poisson distribution with parameter the expected number of prey in an ocean volume the size of the predator's sight sphere, viz. $\mu \frac{4}{3} \pi r^3$, where μ is a density parameter. An inequality analogous to (16) could be set up for the probabilities that exactly zero prey are in sight and the resulting exponentials could be easily simplified. However, this approach is density dependent, is time dependent, and makes the assumption of uniform distribution of fish throughout the ocean.

The approach taken in this paper, by isolating in the expectations of (16) the components which deal with the distribution of distance between two particular fish, has definite advantages. From the definitions and (14) and (15) it can be seen that we are concerned with the probability distribution of a single d_{ik} or $d_{k'}$, where i, k may take on any admissible values, for a fixed point in time with fixed n_p, n_f. Thus the probability distributions for d_{ik}, $d_{k'}$ are not dependent upon the density of predators or prey in the given ocean space. Also, the probability distribution of distance between two fish is the same for any one time as for any other, and so is independent of time as well as density. (This may be said more rigorously as the distance between two randomly placed fish is orthogonal to time so that the probability distribution of distance is the marginal distribution with respect to distance obtained from the joint distribution with respect to distance and time.) Furthermore, the unjustified assumption of uniform distribution of fish is not made.

The probability distribution for d_{ik} must now be considered. It is well known that even non-schooled fish are contagiously distributed, although the cause, perhaps oceanographic conditions, perhaps food concentrations, is unknown. Thus non-schooled fish may be thought of as uniformly distributed for only small regions of ocean. Within such a region, the probability that there will be a second fish at some distance from a first fish increases as a power function. As the region considered exceeds the contagion region, however, the density of fish becomes less, so that the probability of a second fish at some distance from a first fish will decrease again as the distance becomes great. It is obvious that the derivative (rate of change of distance) must exist for all distances. Thus our curve is smooth in the vicinity of the maximum and must be some sort of bell-shaped curve. The functional form of this curve is unknown. However, we are dealing with a comparison of probabilities at the extreme left of the curve, i. e., from zero to at most $r + r'$, which may reasonably be restricted to the order of a few hundred feet or less. Now for any stable ecological system, the predator will not be very frequently in sight of prey, and thus $E(d_{ik})$ is considerably larger than either or the sum of r, r'. If $E(d_{ik})$ were not much larger than either or the sum of r, r', the predator would encounter the prey often and would eat the prey rapidly and reproduce rapidly. The number of prey would soon reduce to a number implying fewer encounters, which in turn implies an $E(d_{ik})$ much larger than either or the sum of r, r'.

We may now assume that the predator and prey relationship is stable or but slowly changing and thus that we are dealing with the extreme left tail of the distribution. For this tail and the small distances involved, we shall assume uniformly distributed predators and non-schooled prey.

The distribution of $d_{k'}$ is complicated by r'. A predator sights the school if he comes within the distance of $r + r'$ of the centre of the school. If we think of a single fish as a school of size one, d_{ik} is the distance from the kth predator to the centre of this school. The generalization to thinking of d_{ik} as the distance to the centre of any size school is obvious if we now speak of the ith school rather than the ith fish. Then $d_{k'} = d_{ik} - r'$. Let us denote $E(d_{ik}) \equiv \mu$ and $E(d_{ik}{}^2) - \mu^2 = \sigma^2$ and assume finite means and variances throughout. If r' is taken as constant,

$$E(d_{k'}) = E(d_{ik} - r') = E(d_{ik}) - r' = \mu - r'. \text{ Also}$$

$E(d_{k'}{}^2) - E^2(d_{k'}) = E(d_{ik}{}^2) - 2r'E(d_{ik}) + r'^2 - (\mu - r')^2 = E(d_{ik}{}^2) - \mu^2 = \sigma^2.$
If r' is taken to be a variable with mean $\mu_{r'}$ and variance $\sigma^2_{r'}$,
$E(d_{ik}r') - \mu\mu_{r'} = \text{cov}(d_{ik}, r') = 0$, and it is simple to show in a similar fashion that $E(d_{k'}) = \mu - \mu_{r'}$ and $E(d_{k'}{}^2) - E^2(d_{k'}) = \sigma^2 + \sigma^2_{r'}$. We shall take r' as constant.

Now since $d_{k'} = d_{ik} - r'$, (17) may be written

$$\frac{n_e}{n_f} < \frac{P[d_{ik} \leq r]}{P[d_{ik} \leq r + r']} \tag{18}$$

In a stable predator and prey relationship, where μ is much larger than either r or r', and under the assumption of uniformity of distribution of fish for the small distances involved in the extreme left tail of the probability distribution, the right side of (18) reduces to the ratio of volumes of water about the ith prey, representing the predator's effective scouting sight range under non-schooled and schooled prey conditions, respectively. Such volumes reduce to three cases: (i) the prey is at a distance greater than $r + r'$ from either the surface of the ocean or some depth below which the fish are unlikely to go, so that the volumes will be spheres. (ii) the prey is at a distance less than $r + r'$ but greater than r from either the surface or this depth so that one volume will be a truncated sphere, i. e., it has lost its cap at one or the other pole. (iii) the prey is at a distance less than r from either the surface and this depth so that both volumes will be spheres truncated on one pole. The last two cases will be discussed for truncation at the top of the sphere, i. e., by the surface of the ocean. If the sphere should be truncated at both poles by both the surface and maximum depth, then the solutions of either or both of cases (ii), (iii) may be used independently to truncate both poles.

Case (i): The volumes are spheres. We have immediately

$$\frac{n_e}{n_f} < \frac{r^3}{(r+r')^3} \tag{19}$$

Case (ii): The smaller volume is a sphere, but the larger volume intersects the surface. Let Φ_1 (>0) denote the angle about the centre of the sphere from horizontal to the intersection of the sphere with the surface. Then (18) becomes

$$\frac{n_e}{n_f} < \frac{\frac{4}{3}\pi r^3}{\frac{2}{3}\pi(r+r')^3 + \frac{2}{3}\pi(r+r')^3(1-\cos\Phi_1) + \frac{1}{3}\pi[(r+r')^3\sin\Phi_1 - (r+r')^3\sin^3\Phi_1]} \tag{20}$$

where the first term of the denominator is the lower half of the volume of the total sphere, the second term is the area of the sector of the great circle between 0 and Φ_1 rotated 2π $\left(\text{explicitly} \int_0^{2\pi}\int_0^{\Phi_1}\int_0^{r+r'} r^2 \sin\Phi_1 \, dr \, d\Phi_1 \, d\theta\right)$, and the third term is the usual formula for the volume of a cone, which of course is the remaining volume of the figure where $(r+r')\sin\Phi_1$ is the distance from the centre of the sphere to the surface.

(20) reduces easily to

$$\frac{n_e}{n_f} < \frac{r^3}{(r+r')^3\,[1-\frac{1}{2}\cos\Phi_1(1-\frac{1}{2}\sin\Phi_1)]} \tag{21}$$

If $\Phi_1 = \pi/2$, (21) reduces to (19), which is obvious since the sphere will not be truncated. For any $\Phi_1 < \pi/2$, the quantity in brackets in (21) is always positive and less than unity, so that the right side of (21) is always greater than the right side of (19), implying an advantage to prey if the centre of the school is less than $r + r'$ but greater than r from the surface (or alternatively if the predator is in the equivalent position, which reduces his effective scouting volume).

Case (iii): Both the smaller volume and the larger volume intersect the surface. Let Φ_1 (>0) denote the angle about the centre of the sphere from horizontal to the intersection of the larger sphere with the surface; let Φ_2 (>0) denote the similar angle for the smaller sphere. Then (18) becomes

$$\frac{n_e}{n_f} < \frac{\frac{2}{3}\pi r^3 + \frac{2}{3}\pi r^3(1-\cos\Phi_2) + \frac{1}{3}\pi[r^3\sin\Phi_2 - r^3\sin^3\Phi_2]}{\frac{2}{3}\pi(r+r')^3 + \frac{2}{3}\pi(r+r')^3(1-\cos\Phi_1) + \frac{1}{3}\pi[(r+r')^3\sin\Phi_1 - (r+r')^3\sin^3\Phi_1]} \tag{22}$$

in which both numerator and denominator of the right side are obtained as the analogous expression in (20). (22) reduces easily to

$$\frac{n_e}{n_f} < \frac{r^3\,[1-\frac{1}{2}\cos\Phi_2(1-\frac{1}{2}\sin\Phi_2)]}{(r+r')^3\,[1-\frac{1}{2}\cos\Phi_1(1-\frac{1}{2}\sin\Phi_1)]} \tag{23}$$

If $\Phi_1 = \Phi_2 = 0$, (23) reduces to (19), which is obvious since the same proportion is truncated from each sphere. Note that for $\Phi_1 > 0$,
$1 - \frac{1}{2}\cos\Phi_2\,(1 - \frac{1}{2}\sin\Phi_2) > 1 - \frac{1}{2}\cos\Phi_1\,(1 - \frac{1}{2}\sin\Phi_1)$
which may be written

$$\frac{\cos\Phi_2}{\cos\Phi_1} < \frac{1 - \frac{1}{2}\sin\Phi_1}{1 - \frac{1}{2}\sin\Phi_2} \tag{24}$$

which is always true since $\Phi_2 > \Phi_1$. Thus, the right side of (23) is greater than the right side of (19), implying an advantage to prey if the centre of the school is less than r from (but not actually on) the surface (or alternatively if the predator is in the equivalent position).

Since (21) and (23) imply an advantage to prey if a predator is too close to the surface or some limiting depth, which may be the bottom, we shall discuss the most conservative result, viz. (19). If (19) be written

$$n_e < \frac{r^3}{(r + r')^3}\, n_f, \tag{25}$$

we see that the number of schooled prey a predator must consume after locating a school of prey in order to nullify the advantage the prey gain by schooling is the fraction $r^3/(r + r')^3$ of the total prey in the school.

If we think of a school of n_f prey as being spherical in shape and having all fish distributed uniformly therein, r' is the radius of this sphere and the prey will be some constant number of distance units, say c, apart along a radius. Then there are $\frac{r'}{c}$ prey along a radius, from which we immediately obtain

$$n_f = \frac{4\pi}{3}\left(\frac{r'}{c}\right)^3 \tag{26}$$

or

$$r' = c\sqrt[3]{\frac{3n_f}{4\pi}}. \tag{27}$$

Thus r' is a function of c, n_f and upon substituting (27) into (25) we obtain

$$n_e < \frac{r^3\, n_f}{\left(r + c\sqrt[3]{\frac{3n_f}{4\pi}}\right)^3} \tag{28}$$

For fixed n_f, as c approaches zero, the right side of (28) approaches n_f, which implies that as the prey in a school draw closer together, a predator must be able to consume more and more nearly the entire school in order to nullify schooling advantage. Here the detection advantage increases as the prey draw close together while the frequency of encounter advantage and predator capacity advantage remain unchanged.

Now let us see what happens when c grows larger. The largest c can grow is r; we are assuming only visual communication in our model so that when $c > r$ the prey cannot see one another and thus cannot communicate so that the school ceases to exist by definition. Then since the most disadvantageous c admissible is $c = r$, let us investigate (28) for $c = r$. r cancels in (28) when $c = r$, leaving

$$n_e < \frac{n_f}{\left(1 + 0{\cdot}6204 \sqrt[3]{n_f}\right)^3} \tag{29}$$

This inequality is violated for most reasonable sizes of n_f. For example, if the predator can eat only four prey, which is rather a small number, the schooling advantage is not gained until the school reaches 1,000,000 in size. It is obvious that fish do not school with distances apart approaching the sight range when visual distances are good, but this result shows that schooling in extremely turbid waters or at night may work to the disadvantage of the prey. There exists considerable observation to indicate that schools tend to break up at night and that there is little schooling in waters having poor visual properties. The exact sight range r at which schooling gives neither advantage nor disadvantage will depend upon n_f, n_e, and c, and can be obtained from (28) for any desired values of these variables.

Some values of n_e from (28) for selected values of n_f, r, and c are shown in Table 1.

Table 1

Values of n_e (rounded to the whole fish), larger than which will violate (28), for various n_f and r with c fixed at 4 feet

(Thus in a school of 1,000 prey distributed 4 feet apart, a predator must consume 514 prey to nullify schooling advantage if the sight range is 100 feet, but only 3 prey if the sight range is 4 feet, i. e., the distance apart.)

n_f	$r = 200$ ft.	$r = 100$ ft.	$r = 10$ ft.	$r = 4$ ft. $(= c)$
1	1	1	1	0
10	9	9	3	1
100	85	72	10	2
1,000	704	514	24	3
10,000	4,913	2,767	39	3
1,000,000	88,877	23,695	57	4

If r and c are assumed to be constant and n_f be given various values, the ratio between schooled and scattered prey, viz. (28) will under conditions of uniform abundance of predators and prey, give the frequency of encounter of schooled prey by the predators. Once a school is sufficiently large so as not to be totally consumed during the period of encounter by a predator, further increases in school size would not increase the quantity of prey consumed under these assumptions.

As n_f is increased, the frequency of encounter is reduced, and assuming n_e constant for each encounter, the average amount of prey consumed per unit time is likewise reduced. Obviously there exists some minimal rate of consumption that will permit the survival of the predator, and some maximal rate that depends upon the digestive capacity of the predator.

Let us further illustrate the use of the inequality (28) with some reasonable values drawn in part from observation. From observations and photographs taken from an underwater observation port on the research vessel of the Honolulu Biological Laboratory, schooled skipjack are about 2 feet apart or about 4 feet between the centres of any two fish. The sight range, r, is conservatively, 100 feet. If a marlin, preying on skipjack, eats during an average encounter with a school, some 40 pounds, and skipjack are abundant enough to supply this amount of prey daily if not schooled, the daily consumption rate will vary with school size as shown in Table 2.

Table 2

Variation of consumption rate by a predator with prey school size based on model in text

School size	Daily weight of fish eaten in pounds
1	40
10	4·68
100	0·55
1000	0·08

A school of 2,000 skipjack of 10 pounds average weight would occupy a sphere of about 31·3 feet in radius, and from (28) the marlin must eat $\frac{(100)^3}{(131{\cdot}3)^3} = \frac{1{,}000{,}000}{2{,}262{,}020} = 0{\cdot}442$ of the school or 8,840 pounds during the period of encounter to nullify the schooling advantage.

To illustrate again, let us note that the average successful purse seine set about a pilchard school in British Columbia produced 35 tons while sets upwards of 100 tons were not unknown (HART, 1933). Schools of other marine pelagic fishes reach similar if not greater magnitude. For a large part of such schools to be consumed by a predator, even assuming that he remains with the school for a long period and that the school permits his presence without disintegrating, is quite impossible. If the prey should adopt the strategy (and there is some evidence that this occurs) of disintegrating the large school when sighted by a predator and later reforming, the predator could not physically remain with more than one segment of the school, which puts physical as well as physiological limits on n_e, and thus schooling could not be other than advantageous to the prey under optimum strategy.

Thus far we have discussed $P[d_{ik} \leq r]$ and $P[d_{k'} < r]$ only in ratio; this is satisfactory if we are strictly comparing advantages of schooling to non-schooling. However, if we should be interested in estimating one or both of these probabilities in order to describe what actually occurs in the pelagic ecology rather than to assess strategies, then we should have to deal with one of the probabilities alone. It is of interest to note that $P[d_{ik} \leq r]$ and $P[d_{k'} \leq r]$ are very nearly zero and approximately equal, since they both represent small areas under the extreme tail of a probability curve. Since we do not know the probability functions exactly, we cannot evaluate exactly these probabilities, but let us demonstrate what happens approximately by taking the bell-shaped curves discussed earlier to be approximately normal. Under this assumption, d_{ik} is a random variable distributed as a truncated $n(\mu, \sigma^2)$, since $0 \leq d_{ik} < \infty$. Using the notation of CRAMÉR (1946) in which

$$\varphi(y) = \int_{-\infty}^{y} n(0,1)\, dt,$$

we have

$$(30)\qquad P[d_{ik} \leq r] = \frac{\varphi\left(\frac{r-\mu}{\sigma}\right) - \varphi\left(-\frac{\mu}{\sigma}\right)}{1 - \varphi\left(-\frac{\mu}{\sigma}\right)}$$

and

$$(31)\qquad P[d_{k'} \leq r] = P[d_{ik} \leq r + r'] = \frac{\varphi\left(\frac{r+r'-\mu}{\sigma}\right) - \varphi\left(\frac{r'-\mu}{\sigma}\right)}{1 - \varphi\left(\frac{r'-\mu}{\sigma}\right)}$$

which are approximately equal.

To illustrate, let us find parameter values from a situation which may be taken as reasonable. The maxima of r and r' may reasonably be restricted to the order of magnitude of a few hundred feet or less, say 0·03 nautical miles. In the Marquesas Islands, it has been found that schools of skipjack are sighted about every four nautical miles along a transect of ocean surface. It is reasonable that schools average about 10 tons, and that marlin are in weight about 1/50 as abundant. If a marlin weights 200 pounds, then there will be about two marlin per school along the transect, yielding $\mu = 2$ miles. Let us note the similarity between the left-truncated normal and the poisson distribution and use the poisson property that $\mu = \sigma^2$, so that $\sigma = \sqrt{2}$ or about 1·4. Let us take 100 feet = 0·012 as reasonable values of both r and r'. Substituting these values in the probability values of both sides of (21), we obtain respectively

$$\frac{\varphi\,(1{\cdot}42) - \varphi\,(1{\cdot}41)}{\varphi\,(1{\cdot}42)}, \quad \frac{\varphi\,(1{\cdot}43) - \varphi\,(1{\cdot}42)}{\varphi\,(1{\cdot}43)}$$

or, upon evaluating,

$$\cdot 0015940, \quad \cdot 0015590,$$

which are approximately the same.

Discussion

The assumptions made and conclusions reached herein are admittedly not related to the observed behaviour pattern of any particular species of fish, however, the relationships of school size of prey and encounter frequencies between prey and predators may, for a particular prey-predator combination, be a more complex situation elaborated from that described here. For example, predators may attempt to remain with a school of prey even though satiated, and it is not unlikely that a large school of prey may leave an easily detectable trail of odour behind for a predator to follow. While fish schools of some species do remain together during darkness as indicated for the California sardine by a night fishery (LINDNER, 1930) yet even here the dispersion of tagged fish through the stock as indicated by recovery patterns would argue that a substantial interchange of individuals among schools must occur at least which suggests the possibility of the dispersal and reforming of schools.

The general lack of field data concerning the behaviour pattern for a prey species and its predators renders either the confirmation or refutation of the conclusions reached in this paper by the elaboration of some scheme of predator strategy rather futile. HIATT and BROCK (1948) described the herding of a small school of mackerel scad (*Decapterus*) by a few little tuna (*Euthynnus*) which would seem to constitute a more elaborate strategy than implied here. We do not conclude that complex strategies do not exist; we do suggest, however, that the relationships among predators, prey, and prey school sizes, described here, may be basic to such strategies.

Summary

The schooling of fish is considered as a mechanism for protection against predation. It is shown that the frequency of detection of prey by a predator is an inverse function of the number of schooled or grouped prey. The quantity of fish that a predator can consume on any single encounter with a school of prey has some average limit, and once school size exceeds this quantity, further increases in school size reduce the frequency of predator-prey encounters without necessarily changing the quantity of prey consumed on the occasion of each encounter, which in turn may reduce the rate of consumption of a prey species by a predator.

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#8

NOTES ON THE SPOTTED DOLPHIN IN THE GULF OF MEXICO

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NOTES ON THE SPOTTED DOLPHIN IN THE GULF OF MEXICO

Moore (Amer. Midl. Nat., 49: 130, 1953) indicated that the spotted dolphin, *Stenella plagiodon* (Cope), is common in offshore waters of Florida. This probably can be applied to the species in offshore waters of the entire Gulf of Mexico, and along much of the Atlantic seaboard. Despite this apparent frequency, Gunter (U.S. Fish and Wildlife Serv., Fishery Bull. 89: 548, 1954) noted that little is known of the natural history of this species. In an earlier paper (Caldwell, Jour. Mamm., 36: 467, 1955) I presented records and random notes for this species in the western Gulf. Knowledge of the spotted porpoise is so embryonic that it is worthwhile to record additional notes, fragmentary though they are, to aid in a clearer understanding of this species. The following observations were made for the most part while I was a visiting investigator, through the courtesy of Harvey Bullis, Jr., on the U.S. Fish and Wildlife Service's M/V *Oregon* during a tuna-fishing cruise to the northern Gulf of Mexico in July 1956. Sight records are summarized in Table 1, and the sighting numbers will in part be used in the discussion below. My identifications were corroborated by William E. Schevill of the Woods Hole Oceanographic Institution after he examined Kodachrome slides made of the living animals in the water. Most of the observations were made with the aid of 7 × 50 binoculars, although the porpoises were usually near the vessel.

In rising to blow, as they ran before the ship's bow, the porpoises usually first exposed the tip of the snout, then the remainder of the head, followed by the arch of the back and the dorsal fin; they then dived beneath the surface. The tail flukes were never seen exposed during a roll.

There are frequent reports of an instinctive animosity by porpoises toward sharks. Contrary to this, at position 4 (Table 1) a large white-tip shark, *Pterolamiops longimanus* (Poey), swam through the midst of several of the porpoises with no apparent notice on the part of fish or mammal.

TABLE 1.—*Observations of spotted dolphins in the northern Gulf of Mexico*

DATE	POSITION IN TEXT	GEOGRAPHICAL POSITION LAT. N	LONG. W	APPROXIMATE DEPTH IN FATHOMS	APPROXIMATE MILES TO NEAREST LAND	NUMBER OF INDIVIDUALS
		Position of M/V *Oregon*				
19 VII 56	1	30°05′	88°28′	10	7	3
21 VII 56	2	28°20′	88°37′	900	53	2
22 VII 56	3	28°35′	88°10′	1160	59	8
24 VII 56	4	28°45′	88°03′	900	60	10
26 VII 56	5	28°50′	87°58′	900	64	2
26 VII 56	6	28°59′	87°49′	800	70	8
26 VII 56	7	28°53′	87°57′	850	65	2
26 VII 56	8	29°22′	88°05′	50	51	8
		Position of sport-fishing vessel				
19 IV 58	9	30°05′	85°46′	11	3	4

Sexual behavior.—In my previous paper (*op. cit.*: 468) I described what was presumed to be copulation. Although the act was not actually witnessed per se, the actions of the porpoises then and during the presently described observations were so similar to those described by Tavolga and Essapian (Zoologica, 42: 12f., 1957) for captive *Tursiops truncatus* (Montague), and to those I have observed for that species in captivity, that it was assumed precopulatory and copulatory behavior were the activities witnessed. Some of the porpoises at position 4 appeared to be so engaged. Several pairs of adults, presumably of opposite sex, were observed together. Frequently one turned onto its back or side and swam close to the other, often rubbing at right angles (about the level of the dorsal fin) against the back of the latter, as the second swam in a normal horizontal position. One pair was seen in the assumed copulatory position, with accompanying splashing.

Other actions by adult pairs involved swimming in a horizontal position, but tilted inward and with the anterior regions in contact, so that a V was formed by the pair. At vessel position 4, several individuals were seen to "stand" vertically in the water, with the jaws breaking the surface. When another individual, swimming in a normal position, brushed the vertically positioned one, the latter's jaws were opened slowly and held open for several seconds.

Although it could not be determined whether the act was associated with sexual behavior or mere play, on several occasions spotted porpoises were observed to jump clear of the water—sometimes leaping in a low arc, and sometimes jumping straight up, arching the back, and falling tail first into the water.

The presumed mating behavior shown by the porpoises during this July cruise complements my previous findings and extends the mating season in the Gulf of Mexico at least from early May to the latter part of July.

Color.—Several of the adult-sized animals at positions 3, 4 and 6 had white lower jaws (from tip to gape) and white-tipped upper jaws. The oral edge of the upper jaw also was white. In some of these, the color appeared pink. I have observed similar pink coloration in the light gray or white areas on captive *Tursiops truncatus*, during the summer mating season, and there appears to be an association of such color with breeding. All the individuals in a school were not so marked—about half of the adult-sized porpoises had dark jaws. Nor could the color be linked with sex, presuming the pairs to be of opposite sex, since all three combinations of jaw color were seen in paired individuals.

I have noted previously the calves of spotted porpoises are not spotted, although the ground color, of various shades on different parts of the body, appears to be generally the same at all ages. This was again demonstrated, even more clearly than before, when two adult-calf pairs (presumably mother and calf) were observed for several minutes each as they swam under the bow of a sport-fishing boat at position 9. The close-inshore occurrence of the spotted porpoise at this position, and at position 1, is noteworthy since data given by Moore (*op. cit.*: 131) showed a preference by this species for an offshore habitat.

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SPERM AND PIGMY SPERM WHALES STRANDED IN THE GULF OF MEXICO

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SPERM AND PIGMY SPERM WHALES STRANDED IN THE GULF OF MEXICO

In a summary of whaling-ship log-book records for sperm whales, *Physeter catodon* Linnaeus, Townsend (Zoologica, 19 (1): charts A and B, 1935) listed this species as having been taken in the Gulf of Mexico only from March through July. The only published records of sperm whale strandings in the Gulf include a large male stranded at Port Arthur, Texas, about 10 March 1910 (Newman, Science, 31: 631, 1910); a fetal male stranded at Englewood, Charlotte County, Florida, on 29 August 1939; and skeletal material from Alligator Peninsula, Franklin County, Florida. The last two records were listed by Moore (Amer. Midl. Nat., 49: 127–128, 1953).

The following two sperm whale records are of special interest since they represent the first reported strandings during the winter months in the Gulf of Mexico. A large sperm whale, 48 feet in length, was beached in the vicinity of Naples, Florida, about November or December 1955. Personnel of the U.S. Fish and Wildlife Service measured and photographed the specimen before the carcass was towed to sea by a U.S. Coast Guard vessel (E. L. Arnold, Jr., personal conversation). Although partially decomposed, the animal appears from the photograph to have been a male. A second individual of this species came ashore on the beach about 5 miles northwest of Port St. Joe, Gulf County, Florida, on 9 December 1957. The animal was alive and lived for several hours after its discovery. It was a young individual, as evidenced by its small size (estimated from photographs at 18–19 feet in over-all length) and by the fact that its teeth had not yet erupted through the gums. Photographs also show the animal to be uniformly dark, with the exception of the interior of the mouth, which is white; to have the expected single left-set blowhole; and to be a male. A cold, 16–18-knot onshore wind was reported and this may have aided in effecting the stranding. A similar, but undated, stranding in Ireland of a comparably sized

TABLE 1.—*Measurements of Galveston specimen of Kogia breviceps*

FEATURE EXAMINED	INCHES	THOUSANDTHS
Total length (to notch in flukes)	84	1000
Width of flukes	22	262
Length of left flipper	14	167
Dorsal fin height	7	83
Dorsal fin length	12	143
Snout tip to rear of dorsal fin base	51	607
Snout tip to blowhole	7	83
Snout tip to eye	12	143
Notch in flukes to rear of dorsal base	33	393
Notch in flukes to flipper base	45*	536
Body depth at base of dorsal	20	238
Maximum body depth	22	262
Width of dorsal at base†	11	131

* Measurement estimated from photographs.
† Not included by Gunter, Hubbs and Beal.

individual with non-erupted teeth was reported by Fraser (*in* Norman and Fraser, FIELD BOOK OF GIANT FISHES, WHALES AND DOLPHINS, 1949).

There are apparently only three previous records of the rare pigmy sperm whale, *Kogia breviceps* (Blainville), in the Gulf of Mexico. One of these was a female which gave birth while stranded at St. Petersburg Beach, Florida, in November 1949 (Moore, *op. cit.*: 129). The other two individuals were reported by Gunter, Hubbs and Beal (Jour. Mamm., 36: 263, 1955) from Texas—a female from Mustang Island on 27 December 1948, and a specimen from Padre Island on 7 February 1954. We now add two more Gulf records. The first of these, tentatively identified as a female from photographs, was found ashore about 0800 on 6 December 1957, on the beach within the city limits of Galveston, Texas. Various factors of tides and position of the animal on the beach indicated that it had washed ashore sometime during the night. When first examined at 0930, by Inglis, the animal was still alive. It had a deep wound on its back to the right of the dorsal fin. The wound appeared to have been caused by a shot or a puncture by some spear-like implement, and was probably a contributing cause to the animal's being washed ashore. The day was cold and stormy, with a strong onshore wind. Body measurements, made by Inglis, are listed in Table 1. The skull, unfortunately, was lost, but the remainder of the skeleton will be placed in the University of Florida Collections. A second individual washed ashore dead about 3 miles east of Destin, Okaloosa County, Florida, on about 1 April 1958. The animal, clearly a female from photographs furnished us, was either buried or washed away before measurements could be made. It is roughly estimated from the photographs to have been about 8–9 feet in over-all length. The color was dark above, shading to lighter (but not white) beneath. Hubbs (Jour. Mamm., 32: 408, 1951) noted that a specimen of this species from California had ". . . bracket-like marks . . . disposed on the two sides of the head between the eye and flippers . . . ." Photographs presented in that paper clearly show the marks. The pictures taken of our Florida specimen show similar markings, except that the upper limb of the bracket is only vaguely indicated—giving more the appearance of an L, with the lower limb directed forward. The photographs of our Texas specimen are all from such an angle that only the lower part of the bracket marks can be seen. These are quite clear, but it cannot be stated that the upper portion of the bracket was present. Gunter, Hubbs and Beal (*op. cit.*: 267) noted that photographs of their Texas specimens do not show such marks.

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ACCUMULATION OF RADIOACTIVE POLLUTANTS BY MARINE ORGANISMS AND ITS RELATION TO FISHERIES

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There are many things to consider in studies of the effects of pollution with atomic materials on our fisheries. One needs to know the character of the wastes, areas of possible contamination, characteristics of the receiving waters, factors of dilution and dispersion, and the living organisms in areas that might be affected. There is then the problem of accumulation and retention of components of radioactive pollutants by marine fishery organisms and their foods. To relate these to the problem, it is necessary to have knowledge of the details of their biology and ecology, practices of the fishing industry, technological processing of fishery products, and fishery economics and marketing.

An accumulation of radioactive materials in fish and shellfish is of importance as it affects man. There is considerable worry that radioactive contaminants may reach man in high concentrations through utilization of seafoods and marine products of commerce. There is also concern that the availability of seafoods may be decreased from changes in populations of fish and shellfish brought about by radiation injury.

Possible damage to our seafood resources from pollution with atomic materials is a field of interest to the Bureau of Commercial Fisheries. Contamination of seafoods with radioactive pollutants is also of concern for it is the responsibility of the Bureau to assist and advise the fishing industry in obtaining marketable seafoods and to work with other agencies of the Government in the selection of standards of seafood quality and the prevention of harmful pollution.

To find answers to some of these problems, the Bureau of Commercial Fisheries, through the cooperation of the Atomic Energy Commission, is conducting studies at its laboratory at Beaufort, North Carolina. This laboratory is well situated to consider a number of the important fisheries of the Atlantic Coast. It is so located that estuarine environments, which play a great part in Atlantic Coast fisheries, can be studied. The results of some of the studies have been published and others are soon to appear. General discussions of the findings on accumulation of radionuclides by fishery organisms have been given by Chipman (1958, 1959).

Artificially - produced radioactive materials may be present in marine environments as a result of a number of different activities of man. They may be introduced either through accident or intentional disposal of wastes. Those important to fisheries include fall - out material from nuclear weapons, effluents from different atomic industries and from reactors. Of great concern is the possible contamination of fishing areas from ship reactors. We are thus interested in fission products and radionuclides present as metal corrosion products of reactor cooling systems.

Although all such wastes have the common characteristic of being radioactive, they differ greatly in almost every other respect. Present are radioisotopes of chemical elements in specific chemical and physical form. When added to sea water, they may change and be present in much different chemical or physical form. Questions arise immediately as to their distribution and fate in a marine environment and their availability for uptake by fishery organisms.

Like other marine life, fish and shellfish often are able to take up radioactive contaminants of the water. If available in proper form, they enter the bodies of these organisms following the usual pathways for the particular element. With very few exceptions, radionuclides enter into the various metabolisms of the element and follow the normal pathways of its excretion. Since elements are often concentrated in the body in specific tissues and organs, their radionuclides are similarly concentrated.

We may consider briefly a few points about biological accumulation and concentration of radionuclides. In accumulation we are concerned with changes in the isotopic composition of an element within a tissue. This means changes in the ratio of the number of radioactive atoms to the total number of atoms present, commonly referred to as the specific activity of the radionuclide. With unequal specific activities between the tissues and the outside environment, passage of the element into the organism, or loss from the organism, will tend to bring about an equilibrium in specific activity wherever the element is present. These rates may be slow or fast, depending on the metabolism of the particular element. With like specific activities at equilibrium, we still may have differences in concentrations of the radionuclide between the tissues or the organism and its environment. This results from differences in concentrations of the total element.

In studies of the radiobiology of fishery organisms, we may wish to know the maximum possible concentration for a radionuclide. If we know the concentration of the element within the body, and also the specific activity of the radionuclide of the element taken into the body, we can calculate, for equilibrium conditions, the concentration of radionuclide that will be present. It is important that the specific activity of the radionuclide entering be considered on the basis of total element taken in from all sources. It is unfortunate, however, that in most situations of pollution we are dealing with uneven and changing specific activities. We are forced to deal with changing concentrations.

We need consider what organisms constitute our fisheries. These may be grouped into the general categories of molluscan shellfish, crustacean shellfish, and teleost fishes of many species. All are very unlike in body structure, body composition, mode of life, life history, geographical distribution, habitat, and response to factors of their environment. It is indeed a great task to consider accumulation of radionuclides and radiation damage for such a large and varied group of organisms, particularly when pollution situations may be quite different in character, duration, and extent. However, important fisheries are limited in species taken and generally are located in small geographical areas.

The list of some of the more important fisheries of the Atlantic Coast in Table 1 demonstrates these points. By selection of fisheries for study in relation to their importance, we can narrow our field of work. We are then confronted with a particular biological pattern and mode of life for each fishery selected.

Table 1 is arranged in order of the money value of the catch. This may give a concept of the economic loss that would result from radiation injury to organisms of a fishery. However, a consideration of the number of men and vessels affected may alter the story. It also does not give a concept of the loss of a source of protein food from damage to a fishery.

We may regroup the fisheries listed in Table 1 to show their order in poundage landed. The list thus arranged is given in Table 2. Except for the menhaden and others entering industrial fisheries, such a list may indicate their value as food for man. However, differences exist in the importance of certain fisheries in particular areas. For example, the mullet fishery of the South Atlantic is important only in certain market areas.

We may now consider phases of biological accumulation of radioactive materials. There are a number of general principles of biological accumulation that apply to fishery organisms. However, we must further consider how these fit the biology of a particular organism and the fishing practices of a fishery. We can never obtain quantitative answers as to hazardous levels of pollution without this detailed information.

One general consideration of importance is the availability of radioactive materials for uptake by fishery organisms. Sea water, although having elements present in ionic form, is a suspension of particles of many sizes. These are inorganic and organic; living and non-living. Many of the radionuclides added to sea water become associated with the particles present, including living phytoplankton cells. We have found nearly all the fission product radionuclides, and also those of the trace metals, associated with marine plankton cells when added to sea water cultures. Even the rare earth radionuclide, cerium-144, which was chiefly present as particles, was associated with these cells in great amount (Rice and Willis, 1959).

Table 1. Important Fisheries of the Atlantic Coast in Order of Value[1/]

Common name	Scientific name	Area of greatest catches	Atlantic Coast landings 1956 Thousands of dollars
Oyster	Crassostrea virginica	Chesapeake Bay	24,984
Menhaden	Brevoortia tyrannus	Middle Atlantic	20,021
Northern lobster	Homarus americanus	Maine	11,908
Sea scallop	Placopecten magellanicus	Massachusetts	10,822
Haddock	Melanogrammus aeglefinus	Massachusetts	9,587
Shrimp	Penaeus setiferus Penaeus aztecus Penaeus duorarum	South Atlantic	7,825
Hard clam	Venus mercenaria	Middle Atlantic	6,044
Ocean perch	Sebastes marinus	Massachusetts	5,723
Blue crab	Callinectes sapidus	Chesapeake Bay	5,640
Fluke	Paralichthys dentatus	Middle Atlantic	3,654
Sea herring	Clupea harengus	Maine	2,409
Soft clam	Mya arenaria	Maine	2,349
Cod	Gadus callarias	Massachusetts	2,225
Scup	Stenotomus versicolor	Middle Atlantic	1,994
Surf clam	Spisula solidissima	New Jersey	1,782
Whiting	Merluccius bilinearis Merluccius albidus	Massachusetts	1,683
Blackback flounder	Pseudopleuronectes americanus	New England	1,529
Yellowtail flounder	Limanda ferruginea	Massachusetts	1,481
Croaker	Micropogon undulatus	Chesapeake Bay	1,363
Shad	Alosa sapidissima	Chesapeake Bay	1,282
Sea bass	Centropristes striatus	N. J. and Virginia	1,169
Striped bass	Roccus saxatilis	Chesapeake Bay	973
Bay scallop	Pecten irradians	Mass. to N. J.	922
Butterfish	Poronotus triacanthus	Rhode Island	870
Sea trout	Cynoscion regalis	N. J. to N. C.	793
Pollack	Pollachius virens	Massachusetts	702
Alewife	Alosa pseudoharengus	Chesapeake Bay	672
Spot	Leiostomus xanthurus	Chesapeake Bay	592
Gray sole	Glyptocephalus cynoglossus	Massachusetts	558
Dab	Hippoglossoides platessoides	New England	555
Mullet	Mugil cephalus Mugil curema	South Atlantic	546
Mackerel	Scomber scombrus	New England	485
Spotted sea trout	Cynoscion nebulosus	Florida	482
Bluefish	Pomatomus saltatrix	N. J. and Florida	427

Although there are a number of important radionuclides which may be taken up by marine animals directly from the water, it is necessary to consider here the importance of particles in the sea in passing elements to fishery organisms. As you all know, in the sea the primary food organisms, the phytoplankton, are almost exclusively of minute size. Particle filtration by small marine animals is of extreme importance in passing food elements through the complex food-web patterns of most fishes.

In research studies of the accumulation of radionuclides by fishery organisms we are thus

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[1/] Source: Fishery Statistics for 1956. U. S. Fish and Wildlife Service.

Table 2. Important Fisheries of the Atlantic Coast in Order of Catch[1]

Common name	Scientific name	Area of greatest catches	Atlantic Coast landings 1956 Thousands of pounds
Menhaden	Brevoortia tyrannus	Middle Atlantic	1,537,403
Haddock	Melanogrammus aeglefinus	Massachusetts	152,246
Ocean perch	Sebastes marinus	Massachusetts	151,113
Sea herring	Clupea harengus	Maine	147,901
Whiting	Merluccius bilinearis Merluccius albidus	Massachusetts	93,923
Blue crab	Callinectes sapidus	Chesapeake Bay	81,701
Alewife	Alosa pseudoharengus	Chesapeake Bay	53,517
Oyster	Crassostrea virginica	Chesapeake Bay	49,692
Scup	Stenotomus versicolor	Middle Atlantic	36,266
Cod	Gadus callarias	Massachusetts	35,127
Northern lobster	Homarus americanus	Maine	26,520
Shrimp	Penaeus setiferus Penaeus aztecus Penaeus duorarum	South Atlantic	25,536
Pollack	Pollachius virens	Massachusetts	23,023
Fluke	Paralichthys dentatus	Middle Atlantic	22,675
Sea scallop	Placopecten magellanicus	Massachusetts	20,066
Croaker	Micropogon undulatus	Chesapeake Bay	16,562
Surf clam	Spisula solidissima	New Jersey	15,976
Yellowtail flounder	Limanda ferruginea	Massachusetts	14,643
Hard clam	Venus mercenaria	Middle Atlantic	14,251
Blackback flounder	Pseudopleuronectes americanus	New England	14,233
Sea bass	Centropristes striatus	N. J. and Virginia	11,689
Spot	Leiostomus xanthurus	Chesapeake Bay	11,036
Shad	Alosa sapidissima	Chesapeake Bay	9,672
Butterfish	Poronotus triacanthus	Rhode Island	9,319
Sea trout	Cynoscion regalis	N. J. to N. C.	8,779
Mullet	Mugil cephalus Mugil curema	South Atlantic	8,584
White hake	Urophycis tenuis	New England	6,466
Soft clam	Mya arenaria	Maine	6,116
Dab	Hippoglossoides platessoides	New England	5,908
Gray sole	Glyptocephalus cynoglossus	Massachusetts	5,293
Spanish mackerel	Scomberomorus maculatus	Florida	4,941
Striped bass	Roccus saxatilis	Chesapeake Bay	4,480
King whiting	Menticirrhus americanus	South Atlantic	4,065

compelled to study the accumulation of radioactive materials by phytoplankton and by various zooplankton forms. We must consider particular food webs related to a fishery.

Generally, passage of the radionuclides associated with particles through food webs to our higher fishes and to man depends on absorption of the radionuclides from the digestive tract and accumulation in the body of each of the different organisms. However, molluscan shellfish are filter-feeding forms and are able to concentrate particles from large volumes of water. If continuously available, radioactive particles may accumulate in filtering mechanisms, on body surfaces, and within the digestive tract. These may give a high radioactivity even though the radionuclides responsible for the radioactivity are poorly absorbed and not concentrated within the tissues. We have measured rather high concentrations of cerium-144, ruthenium-106, and others when the entire soft tissues of shellfish were sampled. The greater part of the radioactivity was due to association of particles with body surfaces and their presence in the organs and structures connected with the digestive tract.

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[1] Source: Fishery Statistics for 1956. U. S. Fish and Wildlife Service.

It is the concentration level of a radionuclide in seafood organisms that determines its hazard to man and its ability to cause radiation damage. Consequently, we are concerned with determining concentrations in different organs and tissues. In studies of the body distribution of radionuclides for consideration of radiation damage, we need search for radiation-sensitive critical tissues. Passage of concentrations of radioactive materials to man, however, involves only those tissues utilized as a seafood. For the most part, this means concentrations in muscle tissue. However, there are a number of important exceptions.

Of great importance is the fact that the entire soft tissues of oysters and clams are utilized. These shellfish are known to contain extremely high concentrations of certain metals and can be an important source of the radionuclides of those trace metals present as corrosion products (Chipman, et al., 1958). Other seafoods may be less important if only concentrations in muscle tissue need be considered. Cesium-137, an important fission product, is concentrated in muscles. We have found that clams concentrate cesium-137 to a greater extent than do oysters, which is in agreement with the difference in their body structure as regards muscle tissue. For this radionuclide, the most hazardous of the molluscan shellfish is the scallop, since only the adductor muscle is eaten.

Because of the inclusion of clacified structures in the marketing of some seafoods, such as the marketing of sea herring as Maine sardines, these products can be an important source of strontium-90 to man. In fact, sardines are considered as important as certain dairy products as a source of calcium and strontium.

Because of the nature of the problem of the effects of pollution of marine environments with radioactive materials on fisheries, we must consider the dynamic phases of accumulation and retention of radionuclides by fishery organisms. In this pollution problem, we are apt to be dealing with localized areas of pollution, in which the amount and times of addition of the pollutant may vary. These changes alter the concentration of radioactive contaminants in the organisms of an area. Furthermore, most fishery organisms move and migrate and can pass into and out of polluted areas. This results in changes in the radioactivity of their tissues.

It is conceivable that estuaries are likely to be areas in which the concentrations of radioactive pollutants will be higher than in offshore areas. For the important fisheries of the Atlantic coast, inshore areas, and particularly the estuaries, are of extreme importance. Some species, such as certain shellfish, are limited to estuarine waters. Some fishes are anadramous and enter fresh waters to spawn. Inshore fishes move offshore in certain seasons. Some offshore fishes spend their early lives in nursery areas within estuaries.

In the case of estuarine species, differences in concentration of pollutants within sections of an estuary can be important. The edible blue crab has a migration pattern within estuaries in which the females congregate in the more saline waters for the hatching and release of zoea while the males remain in areas of fresher water. Although adult oysters may be considered sedentary, they are moved about by oystermen in transplanting operations.

In view of the facts that pollution of marine waters may be localized or transitory and fishery organisms move about, we in fisheries research have concerned ourselves with measurements of the rates of accumulation and loss of radionuclides and the effects of season, temperature, salinity, growth, etc., on these rates. These are considered in relation to the biology of our seafood organisms and to fishing practices. All are important in attempting to evaluate pollution in reference to concentrations of radioactive materials in the tissues of fish and shellfish at the time of capture or harvesting, or at critical times in their life histories.

We may now turn to a consideration of radiation damage. It is generally agreed that any ionizing radiation may be injurious to living tissues. However, there are small amounts of radioactive materials in living things and some artificially-produced radionuclides are being incorporated. There arises the question of accumulation levels above which serious injury will occur.

Based on the best available information as to the effects of ionizing radiation on human tissues, permissible body burdens of many radionuclides have been established (National Bureau of Standards, 1953). With consideration of the amount of water consumed and of body accumulation, physical decay of the isotope, retention time in the body, the maximum permissible concentration (MPC) for a particular radionuclide in drinking water has been designated. The amounts present in foods ingested by man have likewise been limited to prevent the building up of an excessive body burden.

It is often stated that waters polluted with radioactive materials contain various radionuclides at concentrations well below their MPC values for drinking water. One is led to believe that this also means that these concentrations are also safe levels for aquatic life. This does not necessarily hold true. Aquatic organisms differ from humans in elemental composition, body structure and function, and mode of life. Actually we do not know permissible body burdens for various radionuclides for aquatic life. We are not in a position to state permissible levels of concentration in the water in which they live nor in the foods which they ingest.

To establish such values we need yet to know the organs and tissues of these fishery organisms that are critically sensitive to radiation. These may well be specialized larval structures or tissues. We then need to know the permissible amounts that can be concentrated in these organs and tissues and relate this to the total amount of element present and to the specific activity of the water or food material.

Again, we need information on the MPC value as regards a particular fishery organism. For instance, we know for the grass shrimp, Palaemonetes pugio, concentrations of cesium-137 in the body and in the water which bring about a delay in larval development and which delay or prevent metamorphosis. Such concentrations, if present in estuaries, might also delay development of blue crab larvae or prevent the change from megalops to crab. Shrimp larvae of the genus, Penaeus, however, hatched outside the estuary have completed metamorphosis to the adult form when they enter the nursery grounds of the estuary.

Radiation damage to fishery organisms is important in so far as it changes populations. We are dealing with wild populations in which only the fit survive. For fishery organisms, continuation of the population is usually dependent on the production of great numbers of eggs with only a few of those fertilized reaching maturity. Conditions for survival are often very precise and restrictive. There is evidence, for example, that metamorphosis in the blue crab can take place only within a certain range of salinity. The oyster produces fabulous numbers of eggs. Of those fertilized, only a few continue through elaborate larval stages during which mortality is very great. On reaching a stage for attachment, some find a suitable surface and a large number may attach to a single oyster shell. Because of the need for space, only two or three may survive. Even then predation and disease, or even freshets, take a tremendous toll. Genetic changes resulting from radiation damage may be less serious in such wild populations in which mortalities from other causes are so great. However, there is evidence that the number making up the population for certain fisheries is not great enough to maintain itself at current fishing intensities and overfishing may be a serious matter. It is not unreasonable to think that an added mortality from radiation injury might be critical in a particular fishery.

We have some information on the accumulation of certain radioactive pollutants and can visualize how pollution with these materials might affect our seafood industry or our fisheries. We still lack detailed information for most pollutants and for most of our fisheries. This detailed information is essential in order to arrive at quantitative figures in advance of actual pollution.

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BIOLOGICAL ASPECTS OF DISPOSAL OF RADIOACTIVE WASTES IN MARINE ENVIRONMENTS

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Abstract

Disposal of radioactive wastes in marine waters allows for an accumulation of radioactivity by marine life. Such an accumulation by seafood organisms might affect their utilization or availability. Laboratory studies of accumulation of important radionuclides present in different wastes by marine plankton, benthic invertebrates and various species of marine fish and of the biological effects of accumulated radioactivity on these forms are being conducted at Beaufort, North Carolina, as a co-operative activity of the US Atomic Energy Commission and the US Bureau of Commercial Fisheries. These investigations help provide essential information for the formulation of waste disposal practices and the safe operation of nuclear-powered ships in coastal waters. They are useful also in the development of monitoring programmes designed to detect and evaluate hazards from accidental pollution of inshore waters.

ASPECTS BIOLOGIQUES DE L'ELIMINATION DES DECHETS RADIOACTIFS DANS LE MILIEU MARIN

Résumé

L'élimination des déchets radioactifs dans la mer fait la part d'une accumulation d'activité dans les organismes vivant dans ce milieu. Cette accumulation dans les produits comestibles de la mer peut nuire à leur utilisation ou à leur abondance. A Beaufort (Caroline du Nord), les laboratoires du Bureau des pêcheries commerciales des Etats-Unis font, en collaboration avec la Commission de l'énergie atomique des Etats-Unis, des études sur l'accumulation de radionuclides importants provenant de différents déchets, dans le plancton marin, les invertébrés benthiques et les différentes espèces de poissons, ainsi que sur les effets biologiques de la radioactivité ainsi accumulée. Ces recherches permettent d'obtenir des données de base pour l'élaboration de méthodes d'élimination des déchets et l'exploitation en toute sécurité des navires à propulsion nucléaire dans les eaux côtières. Ces études sont également utiles pour l'établissement de programmes de contrôle ayant pour objet la détection et l'évaluation des dangers que présente la pollution accidentelle des eaux le long du littoral.

БИОЛОГИЧЕСКИЕ АСПЕКТЫ УДАЛЕНИЯ РАДИОАКТИВНЫХ ОТХОДОВ В МОРЯ

Резюме

Удаление радиоактивных отходов в моря может вызвать скопление радиоактивных веществ во всех морских организмах. Такое скопление радиоактивных веществ в организмах, питающихся исключительно продуктами моря, может отразиться на возможности их использования и на их пригодности. Лабораторные исследования скопления важных радиоактивных изотопов из различных отходов, обнаруженных в морском планктоне, в беспозвоночных животных морского дна и в различных видах морской рыбы, и биологического воздействия накопленных радиоактивных веществ на эти организмы в настоящее время проводятся в Бофорте, Северная Каролина, в порядке сотрудничества между Комиссией по атомной энергии США и Бюро торгового рыболовства

США. Благодаря этим исследованиям получаются сведения, весьма важные для установления методов удаления отходов и для обеспечения безопасности плавания работающих на атомной энергии судов в прибрежных водах. Эти данные полезны также для развития программ систематического отбора проб, цель которых заключается в обнаружении и оценке риска от случайного загрязнения прибрежных вод.

ASPECTOS BIOLOGICOS DE LA EVACUACION DE DESECHOS RADIACTIVOS EN MEDIOS MARINOS

Resumen

Al evacuar desechos radiactivos en las aguas de mar, es preciso tener en cuenta la acumulación de radiactividad por la fauna y la flora marinas. Tal acumulación por los organismos marinos que el hombre consume como alimento podrían influir en el aprovechamiento o abundancia de esos organismos. Como actividad cooperativa de la U.S. Atomic Energy Comission y del U.S. Bureau of Commercial Fisheries, se están llevando a cabo en Beaufort (North Carolina) estudios de laboratorio sobre la acumulación, por el plancton marino, los invertebrados bénticos y diversas especies de peces marinos, de una serie de radionúclidos presentes en diferentes desechos, así como sobre los efectos biológicos que en dichos organismos ejerce la acumulación de radiactividad. Estas investigaciones contribuyen a facilitar datos esenciales para la elaboración de métodos de evacuación de desechos y para asegurar la navegación sin riesgos por las aguas costeras de buques propulsados por energía nuclear. Son asimismo útiles para el establecimiento de programas de monitoraje destinados a descubrir y evaluar los riesgos derivados de la contaminación accidental de las aguas interiores.

BIOLOGICAL ASPECTS OF DISPOSAL OF RADIOACTIVE WASTES IN MARINE ENVIRONMENTS

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Disposal of radioactive wastes in marine waters allows for an accumulation of radioactivity by marine life. Such an accumulation by sea-food organisms might affect their utilization or availability. Studies of the uptake and accumulation by marine life of radionuclides known to be present in atomic wastes provide essential information for the formulation of waste disposal practices and the safe operation of nuclear-powered ships in coastal waters. They are useful also in the development of monitoring programmes designed to detect and evaluate hazards from accidental pollution of inshore waters. Laboratory studies of accumulation of important radionuclides present in different wastes by marine plankton, benthic invertebrates, and various species of marine fish, and on the biological effects of accumulated radioactivity on these forms are being conducted at Beaufort, North Carolina, as a co-operative activity of the US Atomic Energy Commission and the US Bureau of Commercial Fisheries. In this paper I shall consider aspects of biological accumulation as applied to marine forms and give a brief résumé of some of the results of the laboratory studies. The results reported are based on the findings of the investigators who have been or are now working at this laboratory. I wish to thank them for the use of unpublished data.

Fundamentals of Accumulation by Marine Life

Although radioactive wastes may be dilute when released to the environment and further dilution from mixing and dispersion results in very low concentrations, there is the known ability of organisms to concentrate chemical elements to great degree. Plants and animals of a marine environment selectively concentrate elements from sea-water. The accumulation of a radionuclide is dependent on many chemical and physical factors and also on metabolic processes within the organism.

The extent of accumulation of a radionuclide is dependent on its availability to the organism. It is regulated by the abundance of the element and, to some extent, by the abundance of other elements. If we had complete and reliable information of the elemental composition of our various natural waters and of the organisms of interest, we could calculate for equilibrium conditions the extent of accumulation of a radionuclide. However, equilibrium between the biota and phases of its chemical environment may require a very extended time. Not only need we consider the elements, but we need also to consider chemical compounds and the availability of elements to the biota when in the form of specific compounds. It is quite possible that certain radionuclides added to a marine environment may be present in chemical combinations not readily available to the marine biota. It has been noted, for instance, by DAVIS *et al.* (1) that, although stable iron was abundant in all the organisms of the Columbia River, the isotope iron-59 occurred in substantial amounts only in plankton and sessile algae. It was seldom found in measureable amounts in organisms of the higher trophic levels. The organisms contained much less zinc than iron, but zinc-65 occurred in relatively large concentrations in almost all organisms sampled.

The distribution of pollutants added to the sea is not apt to be uniform. We are therefore confronted with the need of information on accumulation rates and retention times for various radionuclides. The importance of this in biological transport of radionuclides in the sea, particularly through the vertical migration of plankton, has been pointed out by KETCHUM and BOWEN (2). To understand accumulation rates, one must visualize the dynamic state of the elements within the living organism. There is continual replacement of atoms within the chemical compounds of the body, some being shuffled a number of times between different chemical compounds before entering combinations resulting in their excretion. Incorporation of radioactive atoms may result from chemical exchange phenomena or from the formation of new body constituents. With limited exchange, the rate of accumulation of a radionuclide is dependent on the rate of turnover of body constituents. Some are formed and broken down rapidly and others very slowly. We have thus a biological half-life of a radioisotope as well as a physical half-life.

Nature of radioactive wastes added to marine environments

Although pollution can result from atomic warfare or from the testing of atomic weapons, the production and uses of atomic materials by man for peaceful purposes is becoming an important source of radioactive contamination of marine environments. These wastes originate chiefly from reactor fuel processing, operation of research, power, and production reactors, and utilization of radioactive materials in hospitals, industrial plants, and scientific laboratories. They may be classified on the basis of their radioactivity, for it is their level of radioactivity that governs their handling and their disposal. Because of the volumes involved and the widespread origin of low-level radioactive wastes, it is obvious that dispersion into man's environment is necessary and some will enter marine waters. Disposal of high-level wastes in great ocean depths has been considered. These wastes may be classified also on the basis of origin of their contained radionuclides: those with nuclides resulting from the fission of uranium, known as the fission products, and those with induced radioactivity resulting from neutron bombardment, such as those produced in the primary coolant of a reactor from close association with the reactor core. Both fission products and a number of induced radionuclides are important in pollution of the sea. In the latter category are included corrosion products from the reactors of nuclear vessels.

Radionuclide composition of wastes

If we examine the radionuclide composition of the different radioactive wastes entering the marine environment, we find certain ones that may be considered of particular biological interest. These include some of the fission

TABLE I

PER CENT OF TOTAL RADIOACTIVITY CONTRIBUTED BY CERTAIN FISSION PRODUCTS OF BIOLOGICAL INTEREST AT DIFFERENT TIMES AFTER FISSION*

	20 days	90 days	1 year	3 years	10 years	20 years
Sr^{89}	5.0	10.5	2.7	—	—	—
Sr^{90}—Y^{90}	—	—	3.7	17.4	44.0	48.0
Y^{91}	5.6	12.5	3.8	—		—
Zr^{95}	5.9	14.7	7.2	—	—	—
Nb^{95}	2.3	18.0	14.7	—		—
Mo^{99}	1.3	—	—	—	—	—
Ru^{103m}	4.4	7.2	0.8	—	—	—
Rh^{103}	4.2	7.0	0.8	—	—	—
Ru^{106}—Rh^{106}	—	—	4.9	6.0	—	—
I^{131}	5.6	—	—	—	—	—
I^{132}	1.1	—	—	—	—	—
Cs^{137}—Ba^{137m}	—	—	2.9	13.6	36.0	45.0
La^{140}	13.9	1.8	—	—	—	—
Ba^{140}	12.0	1.6	—	—	—	—
Ce^{141}	9.7	8.5	—	—	—	—
Pr^{143}	12.0	11.2	2.6	—	—	—
Ce^{144}—Pr^{144}	2.6	12.0	52.8	42.0	—	—
Nd^{147}	5.0	—	—	—	—	—
Pm^{147}	—	—	5.7	19.0	16.0	3.4
Sm^{151}	—	—	—	1.1	2.5	2.6

* Adapted from data of Hunter and Ballou (1951). CHIPMAN (4).

products and a few radioisotopes of the trace metals. From examination of Table I we find that those fission products contributing most to the total radioactivity up to about three years of age are radioisotopes of the rare-earth elements, or those having chemical characteristics similar to rare earths. Because of their long physical half-life, strontium-90 and caesium-137 are of considerable importance. In instances of pollution of marine waters with fission products, of particular concern are strontium-90, caesium-137, ruthenium-106, zirconium-95, niobium-95, and cerium-144. Besides these fission products, radionuclides of metals are of importance in pollution of the sea. Radionuclides of different metals were present in relatively high amounts in the biota following the tests of nuclear weapons in the Pacific. Almost half the radioactivity of tuna caught following the tests was due to an accumulation of zinc-65. In the giant clam there was a great accumulation of cobalt-60 (3). Also, corrosion-product radionuclides are present in reactor coolant water of nuclear-powered ships and may enter marine waters. Important ones (Table II) are cobalt-60, iron-59, chromium-51, and tantalum-182. They are present in more concentrated amounts on the ion-exchange resins used with ship reactors.

TABLE II

ESTIMATED AMOUNTS OF IMPORTANT RADIOISOTOPES IN REACTOR COOLANT WATER OF THE N. S. SAVANNAH (5)

Isotope Corrosion Products	Concentration(*) (μc/ml)
Co^{60}	1.2×10^{-2}
Fe^{55}	1.1×10^{-2}
Fe^{59}	5.5×10^{-4}
Ta^{182}	1.7×10^{-2}
Cr^{51}	4.0×10^{-2}
Fission Products	
Sr^{90}	1.4×10^{-7}
Zr^{95}	1.4×10^{-6}
Ru^{106}	0.9×10^{-5}
Cs^{137}	1.5×10^{-4}
Nb^{95}	1.3×10^{-6}
Ce^{144}	0.8×10^{-6}

* After 100 days' operation, 1,530 g fuel exposure, with normal purification.

State of radionuclides in sea-water

The physical states in sea-water of some of the elements having radionuclides known to be present in wastes are shown in Table III. For the more important fission-product radionuclides, only those of caesium and strontium are likely to be present in ionic form. Ruthenium, zirconium, niobium, yttrium and the rare earths are probably present chiefly as particles. Of the metals important in pollution, copper and zinc are likely to be present in ionic form while iron and cobalt occur as solid phases.

Liquid radioactive wastes introduced into the sea may contain some radioactive materials which will remain in solution. Others may be precipitated. Still others may become associated with living and non-living particles present in the water through adsorption to surfaces. Alterations in the chemical and physical form of the compounds containing the radionuclides can greatly affect their availability for uptake by the biota. Radionuclides in particulate

TABLE III

PROBABLE PHYSICAL STATES OF ELEMENTS IN SEA-WATER (6)

Element	Percentage in given physical state		
	Ionic	Colloidal	Particulate
Caesium	70	7	23
Iodine	90	8	2
Strontium	87	3	10
Antimony	73	15	12
Tellurium	45	43	12
Molybdenum	30	10	60
Ruthenium	0	5	95
Cerium	2	4	94
Zirconium	1	3	96
Yttrium	0	4	96
Niobium	0	0	100

form may be removed by filter-feeding marine life and so become available to the larger marine fishes. Particulate matter in the sea will tend to settle to the bottom, although the rate of settling may be quite slow. Thus, radioactive materials may enter bottom sediments and, in some form, become available to bottom-dwelling marine life.

Accumulation of radionuclides by marine organisms

Marine phytoplankton

The small phytoplankton are noteworthy for their concentrating ability for almost all the pollutant radionuclides. They are thus able to pass concentrated amounts of radioactivity to small marine animals and to fishes. We have detected in the ash of phytoplankton cells nearly all the radionuclides present in the fission-product mixture added to the water in which they were grown. They had taken up ruthenium-106, cerium-144, yttrium-91, strontium-89, strontium-90 and yttrium-90. The presence of zirconium-95 and niobium-95 was indicated.

Phytoplankton cells accumulate some fission-product radionuclides markedly. There is immediate and great uptake of ruthenium radioisotopes, and also of those of yttrium. Many species take up only small amounts of radiostrontium, but a few do accumulate strontium. A concentration 16,000 times over that of the water was found for a species of *Carteria* (7). In tests employing strontium-89 with traces of strontium-90 and yttrium-90 present as contaminants, most algae became highly radioactive from their great concentrating ability for yttrium. The radioactivity was not from uptake of strontium Rare earth radionuclides are accumulated many thousands of times above sea water concentrations, as shown from the concentration factors for cerium-144 reported by RICE and WILLIS (8) and listed in Table IV. The species of algae tested had concentrated the radionuclide from about 2,000 to almost 4,500 times in 24 hours. The greater part of this uptake was from association of radioactive particles with the plankton cells.

TABLE IV

CONCENTRATION FACTORS OF CE^{144} FOR VARIOUS SPECIES OF PLANKTONIC ALGAE, CALCULATED ON A WET WEIGHT BASIS (8)

Algae	Number of times over sea-water concentration	
	After 0.5 hours	After 24 hours
Carteria sp.	314	2,422
Platymonas sp.	1,843	2,127
Nitzschia closterium	518	1,970
Thallassiosira sp.	2,610	3,346
Amphidinium klebsi	3,001	4,498
Porphyridium cruentum	802	3,344

Marine phytoplankton do not appear to concentrate caesium-137 to any appreciable extent. Table V shows that none of the species tested had a concentration factor, based on wet weight, greater than 3.1. The uptake appears to be related to surface area and it is likely that adsorption plays an important part.

TABLE V

CONCENTRATION OF CAESIUM BY MARINE ALGAE (10)

Algae	Concentration factor*
Bacillariaceae	
Nitzschia closterium	1.2
Amphora sp.	1.5
Nitzschia sp.	1.7
Chlorophyceae	
Chlamydomonas sp.	1.3
Carteria sp.	1.3
Chlorella sp.	2.4
Pyramimonas sp.	2.6
Nannochloris atomus	3.1
Rhodophyceae	
Porphyridium cruentum	1.3

* The concentration factor is reported as the ratio of Cs^{137} in the algae (wet weight) to that in an equivalent weight of sea-water at an apparent steady-state condition.

Marine phytoplankton also accumulates high concentrations of a number of the trace metals of sea-water. Observations have shown that phytoplankton concentrates cobalt-60 to relatively high levels. A rapid and great uptake of zinc-65 was observed for *Nitzschia closterium* when the radioisotope was added to the sea-water medium in which the cells were suspended (9). Under the conditions of test in which the availability was not maintained, the *Nitzschia* cells removed nearly all the zinc-65 of the medium within 24 hours, much of it within the first hour. Experiments are now under way to test the accumulation of zinc-65 and other radionuclides under conditions of maintained availability. An apparatus is now employed which allows for a continuous flow of sea-water culture medium into a suspension of phytoplankton cells in which the cell population is maintained at desired levels.

Marine zooplankton

The small primary consumers in the sea play a very important part in passing nutrients to fishes. These minute animal forms possess filtering mechanisms which allow them to feed on phytoplankton. They are eaten by small fishes which may serve as food for others still larger. The small animal plankton is an important link in passing radionuclides accumulated by phytoplankton to fishes or other animals in the sea.

Observations in the Pacific following nuclear weapons testing have shown a great accumulation of radioactivity in the marine plankton (11). We have observed that marine copepods and other filter-feeding zooplankton forms do rapidly become radioactive when exposed to sea-water in which are suspended radioactive phytoplankton cells and other radioactive particles. High concentration factors can result when such accumulation of radioactive food particles can be collected from large volumes of water.

A great number of the fission-product radionuclides are poorly adsorbed from the digestive tract. Consequently, the accumulation of radioactivity of these by the filtering zooplankton is related to the presence of radioactive particles on the filtering mechanisms and concentrated within the digestive tract. We have observed the rapid loss of cerium-144 by the copepod, *Tigropus californicus*, when radioactive particles were no longer available, the loss apparently from accumulation other than in the body tissues.

A few species of zooplankton have calcareous structures and may concentrate strontium. Many species do not. We have measured concentration factors for radiostrontium of about one for the copepod, *Tigropus*, and less than one for the brine shrimp, *Artemia*. When phytoplankton food is present, however, a concentration of particles filtered from the water with concentrations of strontium may give an apparent concentration factor somewhat greater than 1, particularly if the factor is calculated per unit volume of water disregarding the abundance of phytoplankton cells.

As for the other radionuclides, experiments have shown almost no accumulation of caesium-137 by the copepod, *Tigropus*. Exposures to sea-water containing the radionuclides for periods up to 24 days resulted in concentration factors from 2 to 4 times that of the water. We have observed that zinc-65 and cobalt-60 were taken up by *Tigropus* with relatively high concentrations resulting.

Bottom-dwelling invertebrates

With the addition of radioactive materials to the sea there is very marked uptake of radioactivity by bottom materials. The sorption properties of bottom materials is great, as is also that of suspended solids, both living and inanimate, which gradually settle to form bottom sediments. All have a great ability to remove substances from solution. There is need for considerable study of the return of such bound materials to the water and to the biota inhabiting the bottom, which may in turn make these materials available for pelagic organisms.

A species of benthic foraminifera, *Discorbis floridana*, held for 40 days in sea-water to which had been added mixed fission products was found by MARTIN (12) to have very high concentration of those radionuclides that are most insoluble at the pH of sea-water, including zirconium-95 and ruthenium-106. These protozoans had not concentrated strontium-90 and contained no caesium-137.

Accumulation of pollutant radionuclides by benthic organisms which obtain ll or part of their food by ingestion of detritus which has settled to the bottom s of considerable importance, particularly by those living within estuaries nd in coastal waters and utilized as food by man directly or serving as food rganisms for economically important fish and shellfish.

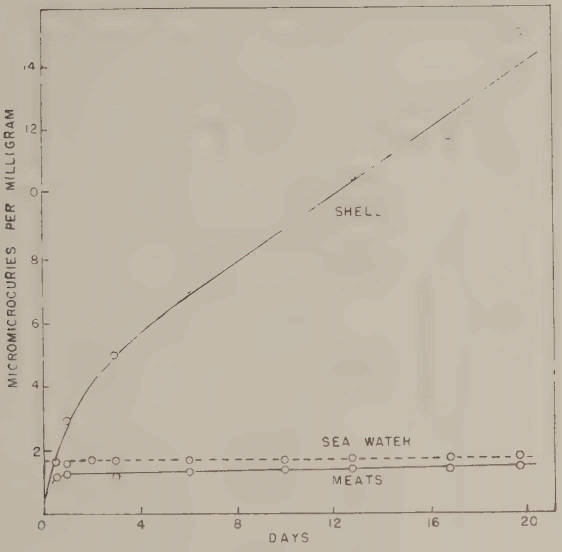

Fig. 1

Experimental work at our laboratory has shown that oysters, clams, and scallops accumulate many fission-product radionuclides. Strontium-89 and strontium-90 are concentrated in their calcareous shells. There is no accumulation of strontium radioisotopes in the soft tissues of the body. The curves of Fig. 1 show the uptake of strontium-85 by the hard clam, *Mercenaria mercenaria*, as an example of one such test. It will be seen that the uptake of the strontium-85 by the edible meats was rapid, but the concentration during the 20 days of observation never equalled that of the water. Caesium-137 is accumulated to relatively high levels in the soft tissues of shellfish. There is a more rapid uptake by the tissues other than muscle than there is in muscle itself. However, the highest concentrations are reached in time in the muscles, as can be seen in the curves of Fig. 2, which shows the accumulation of caesium-137 by the bay scallop, *Pecten irradians*. Clams concentrate caesium-137 to a greater extent than do oysters, which agrees with differences in the amount of muscle tissue present in the two forms. In general, these shell-fish have concentration factors for caesium-137 from about 20 to 50 times that of the surrounding sea-water, depending on the organism and the tissue concerned. The rare-earth radionuclides and ruthenium-106, taken up by the molluscs as particles or with phytoplankton cells given as food, were accumulated to some extent. However, the accumulation was chiefly that of an association of the particles with body surfaces and their presence in the organs and structures connected with the digestive tract. Oysters and clams fed for several hours each day with phytoplankton cells made radioactive from an accumulation of cerium-144 took up only a very small amount of the total radionuclide fed over a period of 28 days. Following the initial uptake there was virtually no further accumulation.

Oysters, clams, and scallops contain very high concentrations of zinc and can concentrate zinc-65 to extremely high levels (9). They also concentrate radionuclides of other metals very markedly. We have observed uptake of considerable amounts of cobalt-60 by hard clams. The great concentrating ability of lamellibranch molluscs for pollutant metal radionuclides is noteworthy. We are now studying the uptake and accumulation of many metal radionuclides by shellfish and the various factors regulating accumulation.

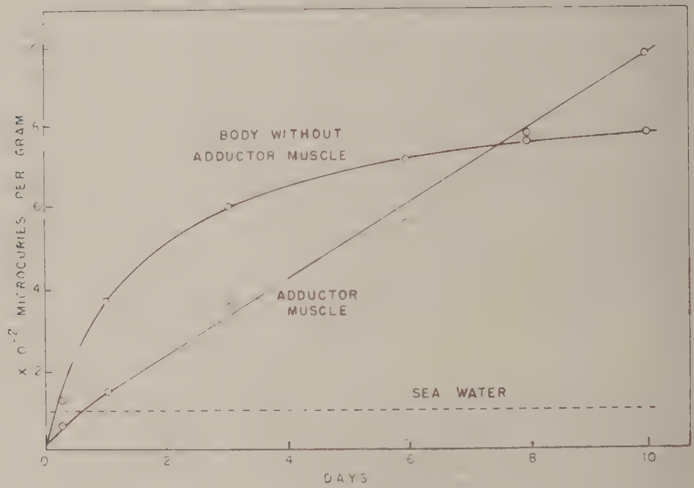

Fig. 2

Only small amounts of the radioactivity of mixed fission products administered entered the body tissues of the edible blue crab, *Callinectes sapidus* and the shrimps or prawns of the genus *Penaeus*. Of that which entered, the greater part was present in the internal organs. Daily oral doses to the blue crab resulted in a gradual accumulation of radioactivity in the shell and in the edible muscles. In these crustacean shellfish there is an accumulation of strontium radioisotopes in the shell and other calcified structures. Moulting resulted in the loss of the concentrated radioactivity. We have found no concentration of radiostrontium in the muscles. Caesium-137 is concentrated in the edible meats. Further studies are under way on the accumulation of radionuclides by crabs and shrimps. Experiments employing the common prawn, *Palaemonetes pugio*, which may be reared and grown with relative ease in the laboratory have shown concentration factors for caesium-137 after long periods of exposur to sea-water containing the radionuclide of about 25 times that of the water n some instances exposure to radioactive sea-water was started with appeaance of the eggs and was continued through the zoeal stages and metamorphosis to the adult form.

Marine fishes

Marine fishes are varied in their mode of life. Consequently accumulation of adionuclides by any one group can be quite different from that by another. There are, however, some facts regarding accumulation that apply to fishes generally. Uptake of elements may take place from the seawater directly or from the ingestion of food containing concentrated amounts. The manner of uptake of elements by the different types of marine fishes needs considerable study. We have observed the accumulation of radionuclides by some of the marine fishes.

Croakers (*Micropogon undulatus*) held in sea-water tanks to which mixed fission products of about one year of age were added became radioactive from accumulation of strontium radioisotopes in the bones and scales. The uptake of strontium-89 and strontium-90 was very great, for these contributed only a very small amount to the total radioactivity of the mixture. There was very little radioactivity in other organs or tissues of the fish. Both croakers and bluefish (*Pomatomus saltatrix*) took up only small amounts of the radioactivity of the mixed fission products through the digestive tract. The small amount entering the body was concentrated in internal organs, bone, and scales, the latter two accounting for the greater part of the total radioactivity present. A part of the radioactivity of the internal organs was due to rare-earth radionuclides, but the radioactivity of the bones and scales was primarily from an accumulation of strontium-89 and strontium-90. Bluefish receiving mixed fission products daily for 55 days in their food had relatively high concentrations of strontium-89 and strontium-90 in bones and scales. There was also an accumulation of caesium-137 in body muscles.

From tests with separated fission products it was found that very little ruthenium-106 was taken from the digestive tract by menhaden, *Brevoortia tyrannus*, fed with radioactive plankton (Table VI). Cerium-144 was poorly absorbed from the tract when administered to croakers. With repeated daily

TABLE VI

RADIOACTIVITY OF MENHADEN AFTER FEEDING ON PHYTOPLANKTON CELLS CONTAINING Ru^{106} (13)

(Tissues of 5 fish analysed for each observation)

Time in hours	Per cent of dose			
	Gills	Digestive tract and contents	Remainder of fish	Total in fish
0	0.64	92.39	0.76	93.79
2	0.05	80.09	1.00	81.14
4	1.13	21.15	0.53	22.81
8	0.06	7.99	0.34	8.39
16	0.08	8.50	0.56	9.14
32	0.02	5.23	0.22	5.47
64	0.02	1.48	0.26	1.76
128	0.01	0.05	0.25	0.31

doses, the early concentration of cerium-144 in the liver was followed by an accumulation in bone. Strontium radioisotopes are highly concentrated in the bones, the base of the scales, and other tissues or stuctures having concentrations of calcium, such as the sclera of the eye. There is no concentration of strontium radioisotopes in the edible body muscles of marine fishes. Continuous exposure of young mullets (*Mugil cephalus* and *Mugil curema*) to strontium-85 for 30 days resulted in a concentration factor for the entire fish of only 4.6. In these the greater part of the weight of the fish was due to body muscles, while the radioactivity was from accumulation in bone and scales. In an experiment with the killifish, *Fundulus heteroclitus*, the body muscles had a concentration factor over water for strontium-85 of only 0.15 after exposure for 32 days (Fig. 3).

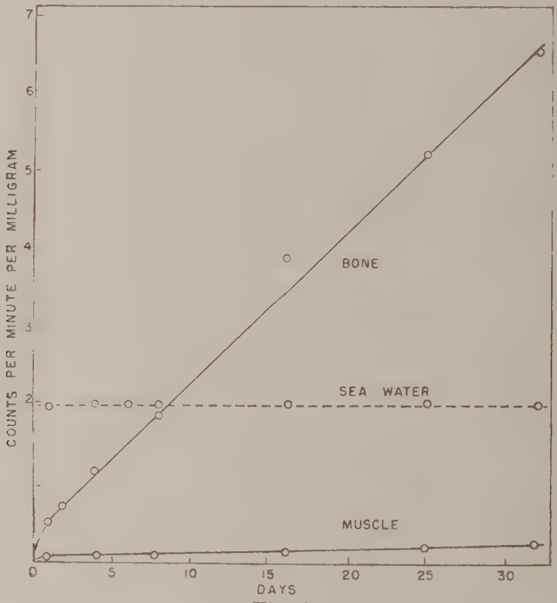

Fig. 3

Caesium-137 is accumulated in the internal organs and the muscle tissues of marine fishes. The long-continued uptake by the body muscles results in significant concentrations. The concentration of caesium-137 in the body muscles of *Fundulus* at 72 days was about 35 times that of the water. In other tests using young spot, *Leiostomus xanthurus*, the concentration of caesium-137 in the muscles after 5 months was 23 times that of the water.

Marine fishes were found to take zinc-65 into the body tissues very rapidly with accumulation in the bone, integument, and muscle tissues. High concentrations of zinc-65 were present in the internal organs, notably in the kidneys. There is a very long retention time for a part of the accumulated zinc-65.

Summary

I have discussed in this paper some of the general facts regarding the uptake of pollutant radionuclides by marine organisms and have given some of the esults obtained in the laboratory studies of accumulation by some represenative species of the different trophic levels. There is no doubt about the need or much more information on uptake and accumulation by components of the marine biota. Problems of availability of pollutant radionuclides to living organisms are of great importance. We as yet know very little of the passage of elements through the food chains of the sea. There is a great need for studies of the foods and feeding habits of marine animals. There is need also for information regarding the damaging effects of accumulated radioactivity on marine ife.

All policies developed to regulate sea disposal of radioactive wastes and all monitoring operations must be based on safe disposal practices. What these may be requires the combined studies of marine scientists: chemists, geologists, oceanographers, biologists, and fisheries specialists. Through their continuing research will come assurance that situations will not develop adversely affecting man's utilization of his ocean resources.

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NEW RECORDS OF THE OPISTHOPROCTID GENUS *BATHYLYCHNOPS*, WITH A NOTICE OF NEOTENY IN THE RELATED GENUS *DOLICHOPTERYX*.—Thanks to the kindness of Mr. William Aron of the University of Washington I have examined a fine collection of elongate opisthoproctid fishes from the North Pacific (collected by Mr. Aron during studies supported by the Office of Naval Research, Contract Nonr—477 [10] and by the National Science Foundation). The term "neoteny" in the title and text is used here in the broad sense. See de Beer (*Embryos and ancestors, 3rd edit.*, p. 63, 1958) for further discussion.

These fishes first appeared to be an undescribed species of *Dolichopteryx*; however, further study suggests they are the young of the monospecific genus *Bathylychnops*, hitherto known from only the adult holotype of *B. exilis*.

In the original description of *B. exilis* (Cohen, *Stanford Ichthyol. Bull., 7(3):47,* 1958) four characters were used to separate *Bathylychnops* from *Dolichopteryx*. Three of these characters are discussed in this paper and additional characters are given. Eleven new locality records are listed along with selected counts and measurements (Table 1). In addition, the material is briefly described.

Vertebral count.—The holotype of *B. exilis* has 80 vertebrae; eight specimens X-rayed have 80–84 vertebrae. *Dolichopteryx longipes* (type species of *Dolichopteryx*) has 40–43 vertebrae (see Cohen, *supra cit.* Additional data was obtained from three eastern Pacific specimens in the collections of the Scripps Institution of Oceanography. I thank my friend Alfred Ebeling for the X-ray photographs). The holotype of *D. binocularis* has about 52 vertebrae (count based on an X-ray photograph of the holotype in the U.S. National Museum). Counts are not available for *D. brachyrhynchus* and *D. anascopa*, the other two species described in the genus.

Teeth.—The type of *B. exilis* has a single row of teeth on the vomer. The vomerine teeth on the smaller specimens are also in a single row, although the compressed bases may overlap to a considerable extent. In contrast to this, all the vomerine teeth which I have examined in *Dolichopteryx* specimens (*D. longipes, D. binocularis, D. brachyrhynchus*) are in two or more rows.

Sexual maturity and structural development.—A remarkable feature of the elongate opisthoproctids is that the early stages of development of many structures, as seen in immature *Bathylychnops,* are also present in sexually mature *Dolichopteryx.* Some examples are: 1. A poorly developed body musculature—The ventral musculature of the body wall is absent; thus the gut is enclosed ventrally by only the peritoneum and the skin. In specimens which are not darkly pigmented ventrally, the entire length of the gut is exposed. The ventral muscle separation continues posteriorly beyond the termination of the gut as far as the anterior procurrent rays of the ventral lobe of the caudal fin. In addition, there is a shallower, distinct dorsal cleavage between the epaxial muscle masses of the two sides. 2. Squamation—Scales are vestigially present. 3. Fins—The paired fins are on prominent peduncles which are not connected to the trunk by muscles. The dorsal and anal fin bases are elevated from the body and appear to float in the membranous tissue which surrounds the body. The pelvic girdle is in two separate halves, on either side of the gut. 4. Pigmentation—The skin is mostly transparent; the color pattern is made up of relatively few, but large chromatophores; the body has dark, ventral blotches. 5. Eyes—The condition of the eyes is intermediate between the non-tubular eyes of adult *B. exilis* and the strongly tubular eyes of all *Dolichopteryx* species I have seen. 6. Luminous tissue—Accessory orbital luminous tissue (in addition to the pronounced orbital photophore) is just beginning to develop in two of the largest specimens (112.5 and 124.5 mm. standard lengths). This tissue is present in larger *Bathylychnops* and is absent in small *Bathylychnops* and in all *Dolichopteryx* which I have seen.

Parr (*Bull. Bingham Oceanogr. Coll., 3*(7):*36, 38,* 1937.) and Roule and Angel (*Res. Camp. Sci. Albert I, 79, pl. 4,* 1930.) have illustrated most of the above conditions in *Dolichopteryx.* It is of interest to note that the latter authors described their specimens as larvae.

It might follow from the above data that all *Dolichopteryx* are the young of unknown, *Bathylychnops*-like adults; however, this is not true for at least two of the species. In *D. longipes,* Beebe (*Zoologica, N.Y., 16*:*72, 76, 77,* 1933.) reported large eggs in the ovary of a female 85 mm. (S.L.), a testis in a 35.5 mm. male, and eggs in a female 40 mm. (S.L.). I have seen eggs in the ovaries of a specimen of *D. longipes,* 62 mm. (S.L.) (Bingham Oceanographic Collections no. 2715, examined through the courtesy of Dr. James Morrow). In

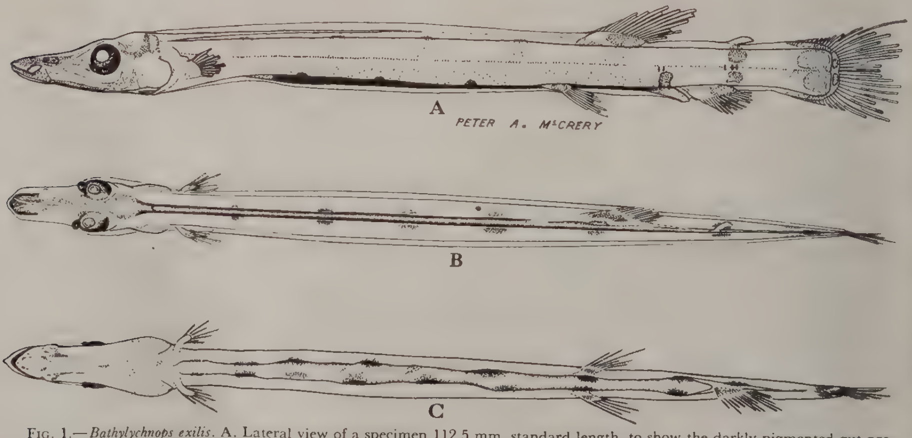

FIG. 1.—*Bathylychnops exilis.* A. Lateral view of a specimen 112.5 mm. standard length, to show the darkly pigmented gut projecting below the lateral musculature. B. Dorsal view of a specimen 112.5 mm. (S.L.). C. Ventral view of a specimen 111.5 mm. (S.L.) to show that the ventral pigmentation is to a degree intermediate between the well-defined blotches of smaller specimens, and the solid pigmentation of larger specimens. Fig. 1A was prepared by Peter McCrery for William Aron at the Department of Oceanography, University of Washington, and emended by Mildred H. Carrington. Fig. 1B and 1C were drawn by Mildred H Carrington.

TABLE 1

LOCALITY DATA AND SELECTED COUNTS AND MEASUREMENTS ON 11 SPECIMENS OF *Bathylychnops exilis*

Latitude N.	Longitude W.	Fishing depth of net (M.)	Time	Date	Standard length (mm.)	Body depth (mm.)	Dorsal rays	Anal rays	Ventral rays	Pectoral rays	Vertebrae (Urostyle not counted)
39°37.5′	135°21.5′	60	0010–0047	7/19/58	112.5	6.5	14	14	7	13	82
39°35.1′	141°53′	225	0308–0406	7/16/58	124.5	8.4	16	13	7	—	81
41°06′	133°02′	60	0007–0045	8/10/58	94.5	4.5	15	14	7	12	82
38°24.9′	139°37.1′	225	1331–1429	7/17/58	101.0	6.0	15	14	7	13	81
42°51.8′	135°28.5′	225	0139–0238	8/11/58	105.0	5.0	16	14	7	13	84
38°34.6′	131°32.2′	400	1655–1810	8/11/58	90.0	5.5	13	13	7	13	81
39°50′	142°10′	60	0004–0042	7/19/58	113.5	4.8	—	—	—	13	84
39°50′	142°10′	60	0004–0042	7/19/58	111.5	4.5	15	13	7	13	80
38°51′	141°58′	120	0127–0210	7/18/58	42.8	—	15	—	7	12	—
38°49.6′	137°56.1′	30	0045–0120	7/18/58	55.0	3.6	14	13	7	13	—
39°45.5′	142°02.9′	120	0126–0209	7/16/58	25.0	—	—	—	—	—	—
38°55.7′	137°36.7′	225	0307–0403	7/18/58	46.0	—	—	—	7	13	—

addition, Parr (*op. cit.*) stated that the type of *Dolichopteryx brachyrhynchus* is a mature male.

Neoteny in *Dolichopteryx* may be an important character in separating this genus from *Bathylychnops*. Additional material of *D. binocularis* and *D. anascopa* is needed to check these species for gonadal development and to examine the development of the structures noted above. These two species may belong in *Bathylychnops*.

Color Pattern of Young Bathylychnops (Fig. 1).—The body is a translucent white, suggesting that the specimens may be transparent in life. The muzzle is dusky; dark pigment is present in the lateral walls of the brain case and visible through the skull. A dorsal and a ventral series of dark blotches are present along the body. The dorsal series consists of 6 pairs of evenly-spaced blotches of dark brown pigment which are located on the inner faces of the epaxial muscle masses. These blotches are plainly visible from a dorsal view. Seen laterally, they are visible through the muscles. The blotch between the dorsal and caudal fins is spread out onto the outside of the muscle masses and forms a saddle over the caudal peduncle. The fifth blotch is immediately below the base of the dorsal fin, which is also dark brown. The base of the caudal fin also bears a dark lateral blotch which, when viewed from above, appears to be number seven of the dorsal series.

Seven to nine blotches are present ventrally. The anterior-most five or six are present on the peritoneum and the overlying skin. One of the blotches lies between the similarly pigmented bases of the ventral fins, while the last blotch is between the hypaxial muscle masses above the darkly-pigmented anal fin base. It also extends up on the sides of the caudal peduncle to where it almost meets the last dorsal blotch. The other dorsal and ventral blotches do not coincide with each other, but alternate. Three of the larger specimens have the ventral series of blotches obliterated by a solid, dark-brown or black peritoneum. Two specimens show an intermediate condition between blotches and solid coloring. The pattern of blotches on a clear peritoneum is evidently a juvenile character as the adult, type of *B. exilis*, has a dark peritoneum.

Viscera.—All specimens observed had an elongate blind sac, similar to the one shown by Beebe (*op. cit.*) in *Dolichopteryx*, branching off from the intestine a short distance behind the level of the pectoral fins and extending posteriorly a considerable distance. A specimen 105 mm. (S.L.) had a sac over 30 mm. long.

In two *Bathylychnops* specimens 105 mm. and 90 mm. (S.L.) the paired kidneys are elongate structures which extend the entire length of the body cavity.

Dorsal fin rays.—A count of 12 was originally given for the holotype of *B. exilis*. This is one lower than the extreme for the material herein reported upon (Table 1). Reexamination of the type shows that the dorsal fin was damaged, and there may have been as many as 15 dorsal rays.—DANIEL M. COHEN, *U. S. Dept. of Interior, Fish and Wildlife Service, Bur. Comm. Fish., Ichthyol. Lab. Washington, D. C.*

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PROCEEDINGS
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NOTES ON A SMALL COLLECTION OF LIPARID FISHES FROM THE YELLOW SEA

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Through the courtesy of Mr. Merrill Newman, I have had at my disposal several liparid fishes collected by him in May of 1953 on the west coast of Korea. The specimens herein reported were trawled at a depth of five to eight fathoms off Chodo Island, approximately 38° 30′ N. latitude, 124° 15′ E. longitude. The material has been deposited in the Natural History Museum of Stanford University.

The purposes of this paper are four: 1. Describe an apparently unknown form. 2. Give a second record of *Liparis choanus* and extend its known range to the eastern shores of the Yellow Sea. 3. Describe the only known male of *L. choanus*. 4. Confirm the observations of Abe (1950, 1955) that some species of *Liparis* lack posterior nostrils.

Counts on vertebrae, dorsal fin rays and anal fin rays have been taken from X-rays.

Liparis newmani new species

Holotype: S.U. 53270, 55.6 mm in standard length.

Diagnosis: A *Liparis* with two nostrils, the dorsal and anal connected to the caudal, the dorsal lacking a notch, the pectoral with a notch, the gill slit extending down in front of seven pectoral rays and with a greater number of pectoral rays than dorsal rays.

Counts and measurements: Measurements in millimeters first, followed by percent of standard length in parentheses. Greatest body depth 12.4 (21.4); width of body at level of anal fin origin 6.5 (8.9); greatest head width 14.5 (25.0); head length 16.6 (28.6); eye 2.8 (4.8); snout length 7.0 (12.1); disc length 6.5 (8.6); disc width 5.0 (9.0); interorbital 7.9 (14.2); gill slit 4.8 (7.2); posterior edge of disc to vent 6.4 (11.5); snout to posterior tip of pectoral fin 27.0 (48.6); dorsal 42; anal 35; pectoral 46, counted on the right fin; vertebrae 45, not including urostyle; branchiosetgals 6.

Description: A slender fish with the greatest body depth immediately behind the head, 4.5 in standard length. Body compressed, deeper than wide, even at the widest point behind the head. Viewed from above or below, body tadpole-shaped, broad anteriorly, strongly compressed behind the level of the anal fin origin. Skin smooth, lacking prickles.

Dorsal fin origin a short distance behind a vertical from the posterior edge of the opercle. Dorsal fin not notched. Dorsal and anal fins connected with the caudal fin to about the middle of the caudal fin length. Distance from vent to origin of anal fin 4.9 in head. Pectoral fin notched, fifteenth ray from the bottom at the apex of the notch. The disc is longer than it is broad. Caudal fin rounded.

The head is broader than it is deep in the opercular region. Viewed dorsally it curves to the broadly-rounded snout. Viewed laterally the tip of the snout is a blunt, almost vertical area. Eye relatively large, 5.9 in head, with a rounded pupil. Nostrils paired, the anterior tubular, the posterior a raised pore. The distance between the two nostrils is equal to the vertical diameter of the eye. The posterior nostril is in line with a vertical from the anterior margin of the eye.

Premaxillary with six to eight oblique rows of tricuspid teeth which are progressively larger towards the posterior margin of the bone. Dentary with about six oblique rows of tricuspid teeth arranged as in the upper jaw. Each pharyngeal carries a broad pad of pointed teeth which oppose smaller but similar pads in the floor of the mouth. The gill rakers are modified into small dentigerous knobs. Gill opening moderate, 3.5 in head, extending down to level of seventh pectoral ray.

Body and head reddish-brown, skin fairly transparent, with many small, brown chromatophores. Pigment cells unevenly distributed on dorsal and anal fins giving them a variegated appearance. Two narrow, irregular, brown bands across the basal half of the caudal. Ventral part of fish in front of anal fin a uniform reddish-brown, lacking spots. Pectorals with a few scattered chromatophores, more thickly distributed dorsally.

Relationships: This species is apparently most closely related to *L. agassizi* of northern Japan, to which it keys out in Burke's (1930: 56) key to the genus. It differs most strikingly from *L. agassizi*, and indeed from any other known *Liparis*, in its high pectoral ray count, 46 in *L. newmani* compared to 32 to 42 in *L. agassizi* (based on counts by the author on 22 specimens in the U. S. National Museum). Another difference is in the color: Burke (1930: 77) gives four types of coloration, none of which is similar to *L. newmani*. Finally, the skin of *L. newmani* is more transparent than the skin of any specimens of *L. agassizi* I have examined.

Liparis multiradiatus is similar in its high fin ray counts, unnotched dorsal, notched pectoral and attached dorsal and anal fins but has more dorsal rays than pectoral rays, a larger eye (7.0 percent of standard length), a larger gill slit (9.8 percent of standard length) and other differences (see Matsubara and Iwai, 1954: 437).

I have also considered the possibility that my specimen may represent a young example of *Liparis tanakae,* a species which has been recorded from Chefoo on the Yellow Sea (Wu and Wang, 1933). In writing of Japanese and Korean material, Burke (1930: 87) states: "Pectoral fin unnotched in the adult, possibly slightly notched in the young." The pectoral of *L. newmani* is definitely notched. Some differences from Wu and Wang's description of Yellow Sea *L. tanakae* are a longer head (3.4 in standard length for *newmani,* 3.7 to 4.3 for *tanakae*), shorter snout (4.2 in head for *newmani,* 2.3 to 2.9 for *tanakae*), and larger eye (5.9 in head for *newmani,* 7.0 to 9.5 for *tanakae*). Unfortunately, the smallest specimen which they report is 180 millimeters in total length, so that differences in proportions may not be significant. Other differences are in coloration, Wu and Wang state immature fishes are grey; and in pectoral ray counts, they state 40 to 42. In addition, their figure shows a specimen with a much blunter head than in *L. newmani.*

Liparis choanus Wu and Wang

Liparis choanus Wu and Wang, 1933, p. 83, Figs. 5 and 6 (orig. descr., two spec. Chefoo, two spec. Tsingtau).

Study material: A male, 90.2 mm in standard length; a female, 85.0 mm in standard length.

Counts and measurements: Measurements in percent of standard length, given for the male first followed by the female in parentheses. Greatest body depth 24.8 (21.1); width of body at level of anal fin origin 9.4 (8.5); greatest head width 24.3 (24.9); head length 24.4 (27.1); eye 4.2 (3.6); snout length 8.3 (8.2); disc length 8.6 (9.4); disc width 8.3 (9.4); interorbital 9.5 (9.4); gill slit 8.3 (7.8); posterior edge of disc to vent 6.1 (9.0); tip of snout to posterior tip of pectoral fin 39.6 (41.9); dorsal 37 (35); anal 31 (30); pectoral 37–35 (37–37); vertebrae 39 (40), not including urostyle; branchiostegals 6.

Sexual dimorphism: The most striking difference between the two sexes is the presence of typical, *Liparis,* thumb-tack prickles on the male. They are abundant over the sides of the body and on the vertical fins, sparse and small on the upper lobe of the pectoral fin, and absent on the body median to the pectorals and on the venter. The dorsal region of the fish from the interorbital area to the anterior part of the dorsal fin has only scattered prickles but bears a profusion of small fleshy protuberances which give the entire area a rugose appearance. The female has smooth skin.

The male has proportionally longer dorsal and anal fin rays than does the female.

The male has a proportionally shorter disc to anus distance than does the female.

Both sexes have a small papilla behind the vent; however, that of the male is slightly larger and has the tip directed posteriorly. The papilla of the female is surrounded by a number of irregular folds which are absent in the male.

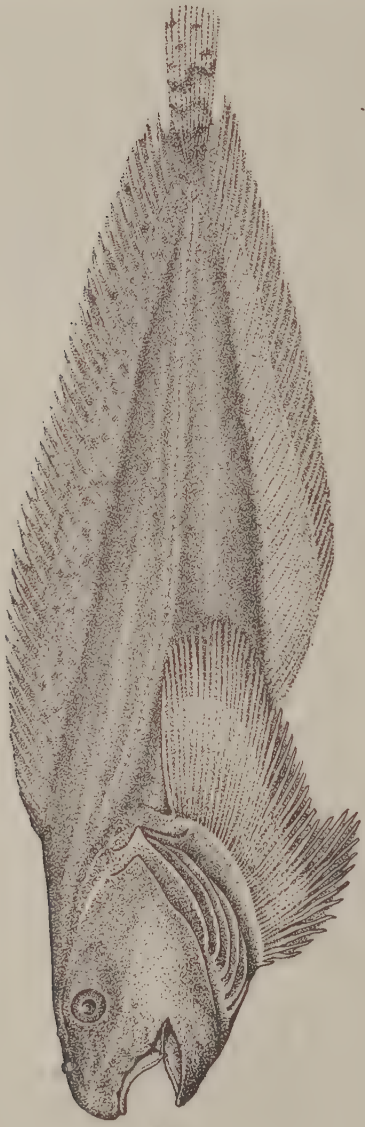

FIG. 1

The specimens at hand agree with the color pattern described for the type material and shown in the figure, with the exception that my material is reddish-brown rather than silvery. Wu and Wang (1933: 81) also describe *Liparis chefuensis*, a species which is reddish and has prickles but in most other respects seems similar to *L. choanus*. *L. chefuensis* was described from five specimens ranging from 120 to 155 mm total length, sex not given; *L. choanus* from four females, 92 to 110 mm total length. I refer my two specimens to *L. choanus* chiefly on the basis of greater similarities in proportions; however, it may well be that *L. choanus*, as described by Wu and Wang, is based on smaller females of *L. chefuensis*.

Nostrils: Many authors who have dealt with the genera of liparid fishes have utilized the presence of two pairs of nostrils to characterize the genus *Liparis*, although Burke (1930: 43) notes the posterior nostril is reduced in some species. More recently, Abe (1950, 1955) has described species which appear to be typical *Liparis* but lack posterior nostrils. A similar situation exists in *L. choanus*. The anterior nostril is present as a prominent, raised tube. The posterior nostril is present only as a very small, fleshy bump which has no opening. In their short diagnosis of the genus *Liparis*, Wu and Wang (1933: 80) state "Nostrils 2." However, in their descriptions of both *L. chefuensis* and *L. choanus* they mention only the tubular nostril.

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EXPLANATION OF FIGURE

Fig. 1. Holotype of *Liparis newmani*, 55.6 mm in standard length. Drawn by Mildred H. Carrington.

REPORT ON THE SCIENTIFIC RESULTS OF THE "MICHAEL SARS" NORTH ATLANT. DEEP-SEA EXPED. 1910
CARRIED OUT UNDER THE AUSPICES OF THE NORWEGIAN GOVERNMENT AND THE SUPERINTENDENCE OF
SIR JOHN MURRAY, K. C. B. and DR. JOHAN HJORT

ISOSPONDYLI

3. ARGENTINOIDEA
(ARGENTINIDAE AND OPISTHOPROCTIDAE)

FROM THE

"MICHAEL SARS" NORTH ATLANTIC DEEP-SEA EXPEDITION 1910

BY

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ORDER ISOSPONDYLI

SUBORDER ARGENTINOIDEA

Professor Hans Brattström of the University of Bergen has forwarded to me for study, argentinoid fishes of the families Argentinidae, Opisthoproctidae and Bathylagidae, collected by the "Michael Sars" Expedition. Brief accounts of the material belonging to the former two families are herein presented. Detailed descriptions of these species along with more extensive literature references are included in the section on the suborder Argentinoidea by the author, in press in *Fishes of the Western North Atlantic* (Mem. 1, pt. 3, Sears Foundation For Marine Research). The valuable "Michael Sars" material of the family Bathylagidae will be reported upon at a later date in connection with a monographic study of this family at present underway. I am indebted to Professor Brattström for allowing this arrangement.

Argentinidae

Nansenia groenlandica (Reinhardt)

Microstomus grönlandicus Reinhardt, 1839, p. 8. (orig. descr.).
Microstoma groenlandicum Gill, 1862, p. 54.
Microstoma groenlandica Gill, 1873, p. 32.
Nansenia groenlandica Jordan and Evermann, 1896, p. 528.
Microstoma sp. Holt and Byrne, 1908, p. 53.

St. 101; 57° 41' N, 11° 48' W; 6—7/8; one specimen 49 mm; taken with 2000 m wire, one specimen 23.5 mm taken with 1000 m wire.

The larger specimen has 13 pectoral rays, 44 lateral line scales (to the base of the caudal); the smaller specimen has 11 dorsal rays, 13 pectoral rays, 44 lateral line scales. In both specimens the ventral fins insert in line with a vertical from the posterior end of the base of the dorsal fin. These few data may aid in eventually establishing the identity of *Nansenia macrolepis*, an Indian Ocean population which may be a good species or may be a synonym of *N. groenlandica* or of *N. ardesiaca*, a Japanese species. See Cohen (1958c), for a more detailed discussion of the taxonomic problems in this genus.

Microstoma microstoma (Risso)

Gasteropelecus microstoma Risso, 1810, p. 356 (orig. descr., in part).
Microstoma microstoma Cuvier, 1817, p. 184.
Microstoma rotundata Risso, 1826, p. 474, pl. 14, fig. 36.
Microstoma argenteum Valenciennes, 1836, pl. 97; 1846, p. 266, pl. 544.
Microstoma mediterranea Cuvier, 1837, pl. 59, fig. 2.
Microstoma rotundatum Günther, 1866, p. 204.
Microstoma argenteum rotundatum Facciola, 1887, p. 193.

St. 56; 36° 53' N, 29° 47' W; 10—11/6; one specimen 19 mm; taken with 300 m wire out.

This species has long been known from the Mediterranean and eastern Atlantic. It recently has been recorded by Grey (1956) from the Gulf of Mexico and by Cohen (1958a) from the eastern Pacific, in a paper which also discusses the confused nomenclature of the species.

Opisthoproctidae

Opisthoproctus Vaillant

Opisthoproctus Vaillant, 1888, p. 105 (type species by monotypy *Opisthoproctus soleatus* Vaillant).
Grimaldia Chapman, 1942, p. 299 (name preoccupied; type species by original designation *Opisthoproctus grimaldi* Zugmayer).
Monacoa Whitley, 1943, p. 171 (replacement name for *Grimaldia* Chapman, 1942.).

Although the two species which I ascribe to this genus are well-differentiated, the differences are far outweighed by such obvious similarities as presence of a ventral light organ with a flat, reflecting sole (Bertelsen, 1958), dorsally-directed tubular eyes, similar body shapes, and others. If, as may well occur, additional species are discovered which are close to one or the other of the two presently

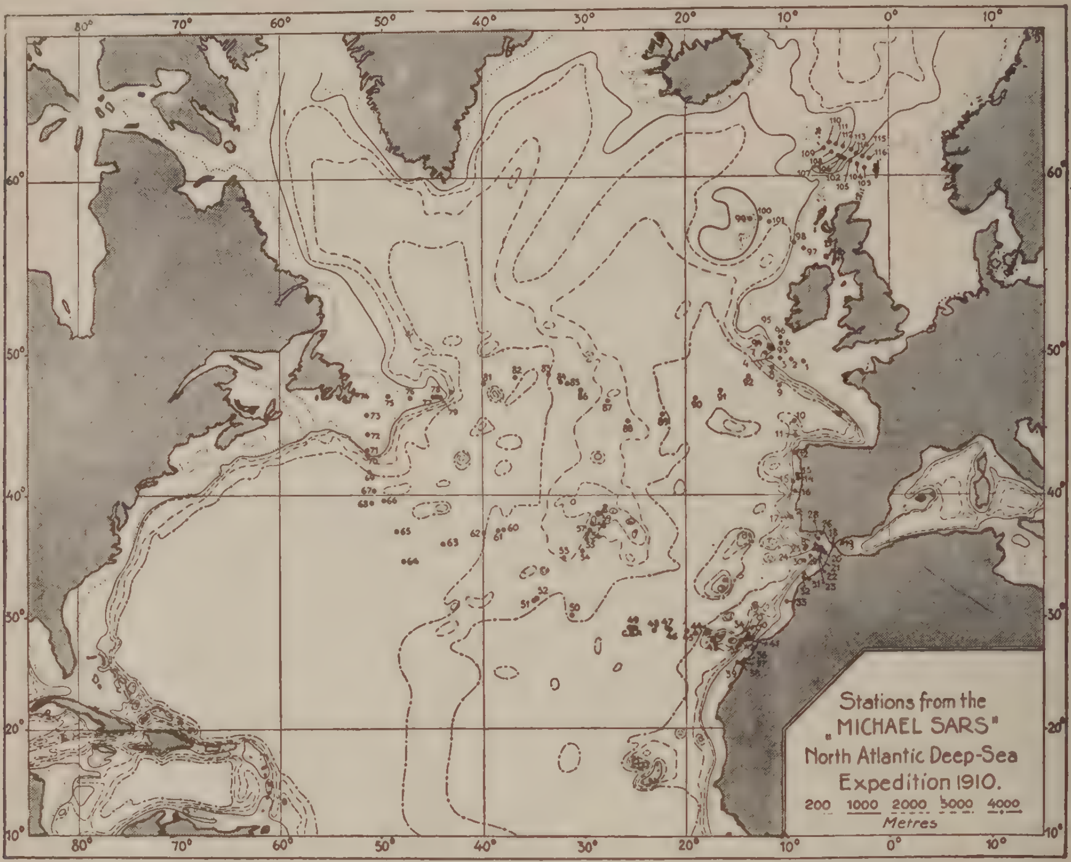

Fig. 1. Stations from the «Michael Sars» North Atlantic Deep-Sea Expedition 1910.

known *Opisthoproctus*, then it may be of value to recognize *Monacoa;* at present however, two monotypic genera serve no zoological purpose.

Opisthoproctus grimaldii ZUGMAYER

Opisthoproctus grimaldii ZUGMAYER, 1911, p. 2, (orig. descr.).
Grimaldia grimaldi CHAPMAN, 1942, p. 299.
Monacoa grimaldii WHITLEY, 1943, p. 171.

St. 23; 35°32′ N, 7°7′ W; 5—6/5; one specimen 15.2 mm; 400 m wire.

St. 49B; 29°8′ N, 25°16′ W; 1/6; one specimen 19.0 mm; 2000 m wire.

In the smaller specimen the sole is not yet completely developed. The larger example is silvery-blue in color. In reporting upon a larger individual of this species COHEN (in press) has noted the appearance of four dark blotches on the posterior surface of the sole, whereas a number of large examples of the related *O. soleatus* had a plain sole. He theorized that when these patterns were illuminated by light reflected through the sole, they might act as ventrally-directed visual cues for species recognition. In the two "Michael Sars" specimens the pattern of blotches is not present, as was the case in a 22.6 mm specimen previously examined; thereby suggesting that the recognition pattern is present only in larger, sexually mature individuals.

Opisthoproctus soleatus VAILLANT

Opisthoproctus soleatus VAILLANT, 1888, p. 105, pl. 13, figs. 1, 1a (orig. descr.)

St. 49B; 29°08′ N, 25°16′ W; 1/6; one specimen 30.5 mm; 3000 m wire.

St. 52; 31°24′ N, 34°47′ W; 6—7/6; one specimen 25 mm; 1200 m wire.

The smaller specimen is in a damaged condition with the sole and body cavity laid open. The inner part of the sole shows the reflecting layer and luminous bulb near the anus, which have been pointed out by BERTELSEN. A well developed swimbladder, 5 mm in length, is present in a retroperitoneal position. It appears physoclistic and seems to give rise, at its posterior end, to both anteriorly and posteriorly running blood vessels in a fashion very similar to that in *Argentina* (COHEN, 1958b). The viscera agree with TREWAVAS' (1933) description of a specimen from the South China Sea except that the intestine is longer and more convoluted (4 loops) than shown in her figure and there are four pyloric caecae instead of the three which were present in her specimen.

In addition to the above material, MURRAY and HJORT (1912, p. 611, fig. 72) list and illustrate a specimen 6.5 cm from st. 64 (34°44' N, 47°52' W) which was not in the material sent to me for examination.

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EFFECTS OF TURBIDITY-PRODUCING MATERIALS IN SEA WATER ON EGGS AND LARVAE OF THE CLAM (VENUS (MERCENARIA) MERCENARIA)

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EFFECTS OF TURBIDITY-PRODUCING MATERIALS IN SEA WATER ON EGGS AND LARVAE OF THE CLAM (VENUS (MERCENARIA) MERCENARIA)

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The effect of suspended materials on mollusks and on the survival and growth of their larvae is of interest to biologists and of considerable importance to shellfish producers. Since several of the most important commercial species are essentially inhabitants of the shallow waters of bays and estuaries, almost all of the grounds used for the cultivation of shellfish are frequently subject to water rendered turbid by natural phenomena, such as floods and storms, and by human operations, such as dredging, bridge- and road-building, etc.

An extensive field study by Lunz (1938) during the dredging of the Intracoastal Waterway of South Carolina showed that the mortality of adult oysters in the dredged area, except where oysters were actually buried by the spoil, was no higher than in areas remote from the dredging operations. Moreover, he found no evidence that the physiological condition of the oysters, as judged by the yield of meats per bushel of oysters, was affected by the dredging operations. He also reported that the intensity of setting of oysters in an area adjacent to dredging operations did not differ from setting intensity in areas remote from such operations, and concluded (p. 134) that "dredging operations apparently had no effect on spawning and setting."

In careful quantitative experiments Loosanoff and Tommers (1948) have shown that as little as 0.1 gram per liter of silt reduced the average pumping rate of adult oysters by 57 per cent. At a concentration of 1.0 g./l. they found the reduction in average pumping rate was more than 80 per cent and reached 94 per cent when the concentrations of silt were increased to 3.0 and 4.0 g./l. They reported that results with kaolin and chalk were similar to those obtained with silt, and that 0.5 g./l. of Fuller's earth, the only concentration tested, reduced the rate of pumping by 60 per cent.

Since the development of techniques for rearing bivalve larvae in the laboratory (Loosanoff and Davis, 1950), these techniques have been used to determine quantitatively the effects of various factors, such as temperature, species of food organisms, crowding, quantity of foods and salinity on the survival and growth of bivalve larvae (Loosanoff, Miller and Smith, 1951; Loosanoff and Davis, 1953; Loosanoff, Davis and Chanley, 1953a; 1953b; Davis, 1953; Davis and Guillard, 1958; Davis, 1958). In the present study they have been employed to determine quantitatively the effect of various concentrations of several materials suspended in sea water on the development of eggs of the hard clam, *Venus* (*Mercenaria*) *mercenaria,* and on the survival and growth of their larvae.

The turbidity-producing materials used in these experiments were clay (kaolin N.F. VII Mallinckrodt), Fuller's earth (dusting powder, McKesson), chalk (precipitated chalk U.S.P. McKesson and Robbins) and silt. The silt was collected from the bed of the Wepawaug River, just upstream from our laboratory. The silt was washed through a 325-mesh, stainless steel screen (meshes approximately 50 microns square) to remove larger particles, collected in a Büchner funnel, where it was washed with distilled water to remove salt, and then dried at 200.0° C. Finally, the dried cake of silt was ground in a jar mill. In the later experiments the Fuller's earth was also ground in the jar mill. Concentrations of suspended material are, therefore, all expressed as grams of dry powder per liter.

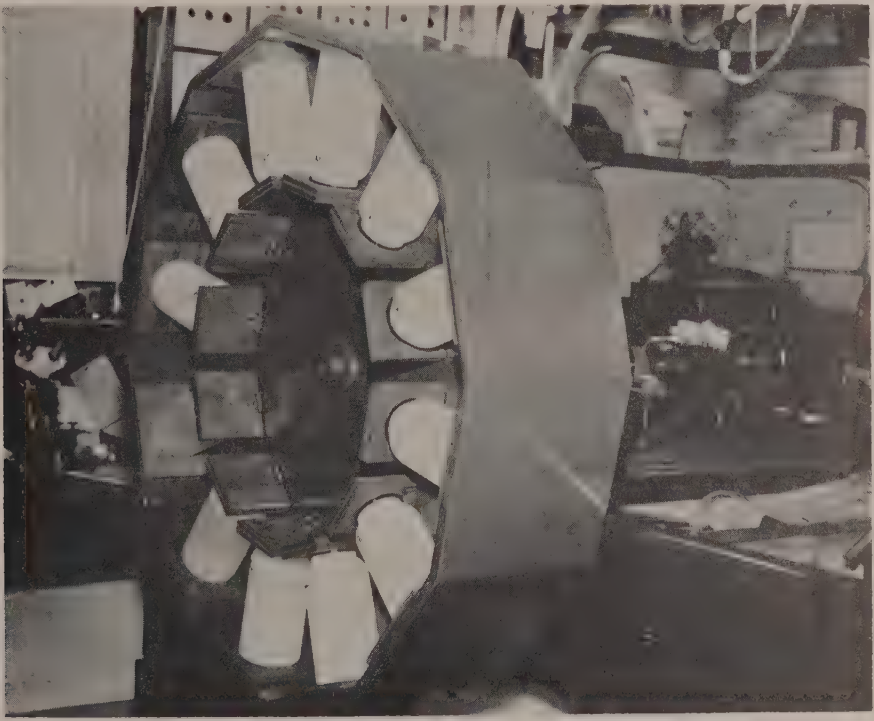

FIGURE 1. Turbidity apparatus showing the wheel and method of attachment of bottles. Motor and reduction gear box indistinctly seen in background.

In making up a suspension, a weighed quantity of the powdered material was thoroughly mixed with sea water and the various experimental concentrations prepared by serial dilution.

The method for obtaining fertilized clam eggs in midwinter has previously been described (Loosanoff and Davis, 1950) as have the methods for determining the percentage of eggs developing to the straight hinge stage, and for determining the rate of growth of larvae (Davis, 1953, 1958).

In the present series of experiments, wide-mouthed, 32-ounce polyethylene bottles with screw caps were used as containers for the larval cultures. To keep the materials in suspension we used a modification of an apparatus which V. L. Loosanoff of this laboratory observed in P. R. Walne's laboratory at the Fisheries Experiment Station, Conway, England. The bottles were mounted on a vertical wheel which, as it rotated, turned the bottles end over end once for each revolution of the wheel. In our apparatus provision is made for 12 bottles on each side of the wheel for a total of 24 bottles so that 12 sets of duplicate cultures can be run concurrently (Fig. 1). The wheel is kept rotating by a constant speed motor working through a speed reducer giving eight revolutions of the wheel per minute. The wheel and attached bottles are enclosed in a plywood box in which the air temperature is thermostatically controlled at 24.0° C., using two 60-watt light bulbs as heaters. A wire mesh shelf is installed in the left upper corner of this box to hold two additional bottles for stationary control cultures (Fig. 2). In practice, one pair of bottles on the wheel is used for moving control cultures, leaving 11 pairs of bottles for duplicate cultures of larvae at each of 11 different sets of experimental concentrations of suspended materials.

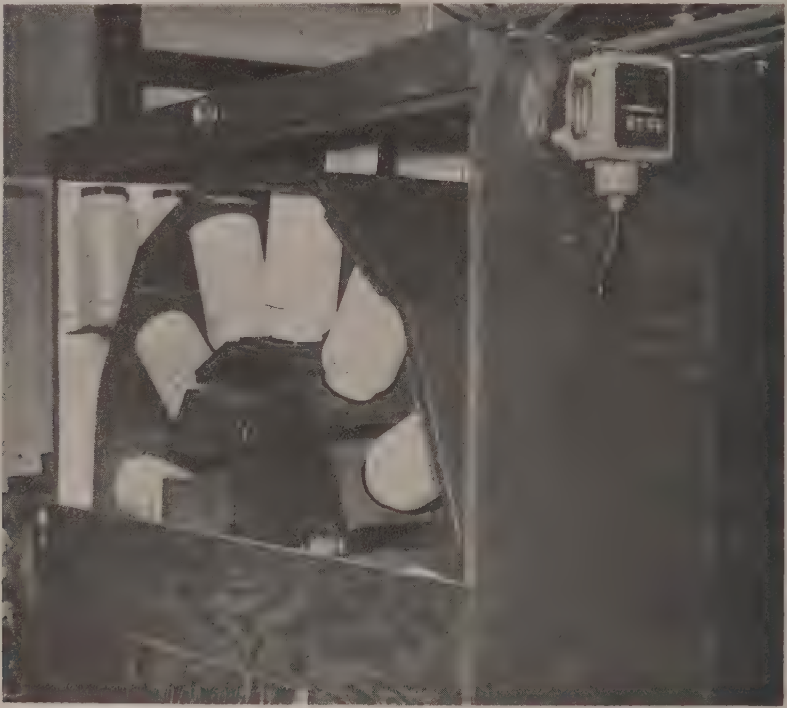

FIGURE 2. Turbidity apparatus showing thermostat control, temperature box and position of stationary control cultures.

The number of larvae suspended in the 800 ml. of sea water and turbidity-producing material in each bottle was initially the same for all cultures in an experiment, but ranged from 8000 per bottle in some experiments to about 15,000 in others. The larvae were fed daily, each culture receiving an equal quantity of a mixture of *Isochrysis* and *Monochrysis*. The larvae were examined every second day when the sea water and its suspended material were changed, but quantitative samples for counts and measurements were taken only when the larvae were 48 hours old and on the twelfth day, when an experiment was terminated.

Preliminary experiments indicated that some fertilized clam eggs could develop into straight hinge larvae in concentrations of either clay (kaolin) or chalk as high as 4.0 g./l., but that none developed to the straight hinge stage in equivalent concentrations of either Fuller's earth or silt. Subsequent experiments, however, have shown that if Fuller's earth was first ground in a jar mill, some larvae developed normally at 4.0 g./l. Similarly, ground silt at concentrations of 3.0 or 4.0 g./l. still completely prevented normal development of clam eggs (Table I). In silt concentrations of 0.75 g./l. or lower, however, there were no significant differences in the percentage of clam eggs developing normally, while with clay, chalk or Fuller's earth there appeared to be a more or less consistent stepwise reduction in the percentage of eggs developing normally with each increase in the quantity of suspended material (Table I).

TABLE I

Percentage of clam eggs developing to the straight hinge larval stage in different concentrations of suspended materials. The number of eggs developing to the straight hinge stage in the stationary controls is considered 100 per cent

Concentration g./l.	Percentages			
	Silt	Clay (kaolin)	Fuller's earth	Chalk
Stationary control	100	100	100	100
Moving control	91			
0.125	95	82	75	
0.188	90			
0.250	96	82	61	approx. 45
0.375	93			
0.500	99	52	41	
0.750	92			
1.000	79	37	57	approx. 30
1.500	65			
2.000	39*	49	50	approx. 39
3.000	0			
4.000	0	42**	45***	approx. 45****

* Averaged 195.80 μ
** Averaged 203.90 μ
*** Averaged 199.60 μ
**** Averaged 189.10 μ
At 12 days when kept in these turbidities only during the first 48 hours after fertilization and then returned to normal sea water.

Although in a silt concentration of 2.0 g./l. only 39 per cent of the eggs developed to the straight hinge larval stage, almost all of these larvae were capable of surviving and growing to metamorphosis (mean length 195 μ at 12 days) if returned to normal sea water. Similarly, larvae developing to straight hinge stage in concentrations of 4.0 g./l. of clay, chalk or Fuller's earth have been reared to setting stage after being returned to normal sea water at the end of 48 hours.

Experiments on the effect of suspended materials on the growth of clam larvae that have developed to the straight hinge stage in our usual sea water have shown that such larvae cannot grow in concentrations of clay, Fuller's earth or chalk as high as those at which some eggs developed. For example, there was no evidence that the larvae were taking the flagellates provided as food, and there was no growth of the larvae in a concentration of chalk as low as 0.250 g./l. With either clay or Fuller's earth, 0.500 g./l. was the highest concentration in which the larvae showed evidence of taking food (color in digestive gland) or any increase in size (Fig. 3). In cultures receiving higher concentrations of clay or Fuller's earth, many larvae ingested some of the suspended particles, apparently in sufficient quantity to block the digestive tract and cause death. Kaolin in a concentration of 0.500 g./l. caused approximately 50 per cent mortality in 12

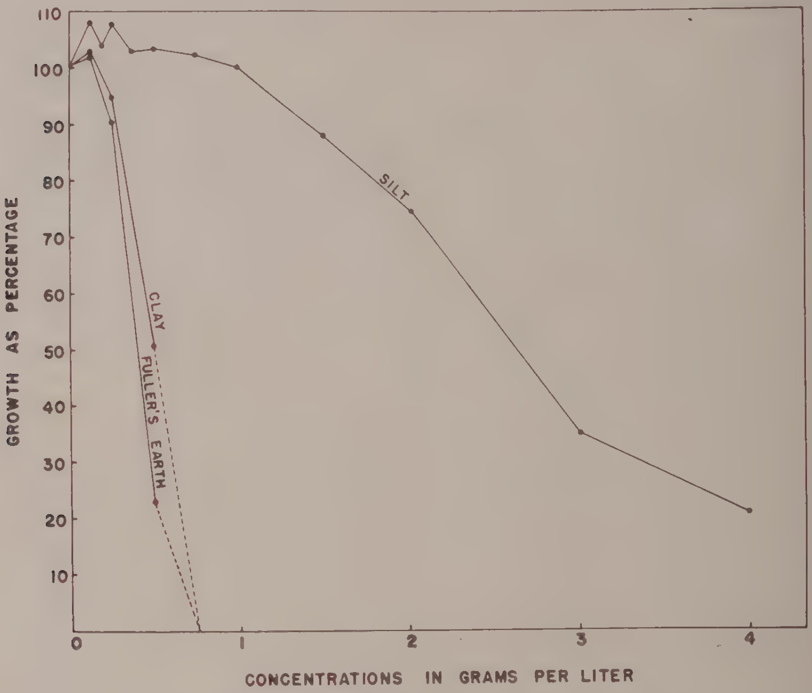

Figure 3. The 12-day increase in mean length of clam larvae, grown in different concentrations of suspended materials, plotted as percentages of the increase in mean length of larvae in control cultures. Each point represents the average for 50 larvae from each of duplicate cultures in each of two experiments.

days and almost complete mortality at all higher concentrations. There was no appreciable mortality of larvae in 0.500 g./l. of Fuller's earth in 12 days, but at all higher concentrations mortality exceeded 90 per cent.

When silt was used as the suspended material the results were quite different from those with clay, Fuller's earth or chalk. Clam larvae showed evidence of taking food (color in digestive gland) even at a concentration of 4.0 g./l. of silt, but growth was negligible, and it is doubtful if any larvae in natural waters could reach metamorphosis in either 3.0 or 4.0 g./l. of silt. Growth of most larvae was also considerably retarded by concentrations of 2.0 g./l. or even 1.5 g./l. of silt, but some larvae under these conditions had reached setting size (maximum length 185 μ and 200 μ, respectively) by the twelfth day. Growth of clam larvae was approximately normal in 0.750 g./l. of silt and, at all lower concentrations, was somewhat better than that of larvae in the control cultures (Fig. 3). There was no appreciable mortality of clam larvae, within 12 days, in any of the concentrations of silt tested.

Soil particles ranging in size from 62 microns to 4 microns are listed as silts, while particles ranging in size from 4 microns to 0.24 microns are listed as clays. From our experiments it would appear that it is the larger particles (coarse silt 62 to 31 microns) in the silt and unground Fuller's earth, or aggregates of particles in other substances that interfered with development of clam eggs, while the smaller particles, characteristic of the clays, probably had little effect on egg development. The results of experiments on growth of larvae, however, seem to indicate that the larger particles, characteristic of coarse silts, may have little effect on growth. It seems to be the smaller particles, as in clays, precipitated chalk, and finely ground Fuller's earth, which are about the size of food cells, that interfere most with growth of larvae. This interference appears to be primarily mechanical through blockage of the digestive tract, but there is some indication that it may also have been, at least in part, an indirect result of an adverse effect of the suspended materials on the food organisms.

The more rapid growth of clam larvae noted in lower concentrations of silt and at the lowest concentrations of clay and Fuller's earth is perhaps due, in part, to chelation of toxic substances, and with silt, in part, to positive growth factors. An improvement in the rate of growth of algal cultures upon addition of soil extract has long been known to botanists, and soil extract has been a basic ingredient in many of the media for algal cultures.

The author wishes to express his appreciation of the suggestions and constructive criticism given by Dr. V. L. Loosanoff, Director of Milford Laboratory. Thanks are also due the mechanical staff who constructed the wheel and constant temperature box, to Kenneth Spencer for preparing the figures and to Miss Rita Riccio for her careful editing of the manuscript.

SUMMARY

1. Some clam eggs developed normally in concentrations of 4.0 g./l. of clay, precipitated chalk or finely ground Fuller's earth, although the percentage developing normally decreased as the concentration of these suspended materials increased.

2. In silt concentrations below 0.75 g./l. the percentage of clam eggs developing normally was not significantly different from that in control cultures but decreased progressively in successively higher concentrations.

3. None of the clam eggs developed normally in silt concentrations of 3.0 or 4.0 g./l.

4. Larvae resulting from clam eggs developing in high concentrations of each of the suspended materials were reared to metamorphosis after being returned to normal sea water at 48 hours.

5. Clam larvae were unable to grow in concentrations of clay, chalk or Fuller's earth as high as those at which some eggs developed.

6. The highest concentration of chalk was 0.25 g./l. and 0.5 g./l. was the highest concentration of clay and Fuller's earth at which clam larvae showed any growth and mortality exceeded 90 per cent at all higher concentrations.

7. In a silt concentration of 0.75 g./l. growth of clam larvae was approximately normal and at lower concentrations was slightly faster than that of larvae in control cultures.

8. In silt concentrations of 1.0 to 2.0 g./l. growth of clam larvae was retarded and at 3.0 and 4.0 g./l. growth was negligible.

9. Even at a silt concentration of 4.0 g./l. there was no appreciable mortality of clam larvae within 12 days.

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Report of the Committee on Oceanography: 'What Does It Mean to Commercial Fisheries?'

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THE FISHERMAN'S LOT is not an easy one. He enjoys no 40-hour week, no guaranteed comfortable working conditions, company life insurance or retirement benefits.

He works long, irregular hours, away from home, in all kinds of weather, and frequently on rough waters. While he is at sea, sleep is a luxury; working days of twelve to eighteen hours are not uncommon.

Fishermen of the north experience extreme cold that freezes their nets and blocks on deck so that they must be thawed with heated sea water. Sometimes their ships become dangerously unstable from frozen spray which must be chopped loose and thrown overboard.

Fishermen of the south sometimes suffer spoilage of their catch in hot weather before it can be delivered to market.

All fishermen suffer the vagaries of nature, of scarcity at one time, overplenty at another. Economic conditions act in various ways to alter prices. These factors add to the fisherman's problems by providing a fluctuating, undependable income.

We lack understanding of nature's effects upon fish abundance, and the effect of these changes upon all types of fishing, whether it be trawling for shrimp or groundfish or harvesting of coastal oysters and clams.

Oyster fishermen work hard to plant shell and seed, often to find that an unknown disease or a hurricane has spoiled the harvest.

Fishing is not now an efficient process. A trawl catch on the Grand Banks may contain five to ten thousand pounds of many types of fish. But our technology and markets allow the use of relatively few varieties. Consequently, a considerable amount of protein is washed back over the side after fishermen have expended labor to catch it.

When fish or shrimp are delivered ashore, they may not be acceptable for market because delays in fishing or weather may have allowed bacterial decay to spoil the catch. Desirable species of food fish often end up in a meal plant, for a fraction of their value had they been landed fresh from the sea.

Improvements in methods of catching and processing fish have been made in recent years, but, on the average, fisheries of the United States have declined in relation to other food-producing industries. Many segments of the United States fishing industry are facing difficulties which are causing them to shrink, to lose their former position of importance in the United States economy. In 1950 there were about fifty large trawlers fishing Georges Bank in the North

Atlantic Ocean. Now there are about thirty. Young men are not entering this industry. It is not attractive to them financially, and the work is hard. The fleet of tuna vessels working out of California ports is shrinking. As vessels become old they are not being replaced. The shrimp industry of the South Atlantic and Gulf Coasts is experiencing economic difficulties from imports and severe competition between fishermen for shrimp available on the fishing grounds.

How can research in oceanography help the fishing industry?

Assume that through oceanographic studies in the future we have complete knowledge of how fish react to combinations of various stimuli, and that we can apply this knowledge to catch fish from wide expanses of the ocean, either from the upper waters or the bottom.

For example, we know now that some fishes make noises and that some will react to sounds of various kinds. They might be attracted or repelled by sound vibrations of the right frequency and intensity.

Similarly, fish will respond to traces of chemicals, to visual barriers such as a curtain of air bubbles, or black dyes, or to light. Their movements can be controlled by electricity.

A fishery of the future, say on Georges Bank, might operate as follows:

An underwater craft, possibly powered by an atomic reactor, is used to scout a five-mile area to chart distributions and numbers of fish. The search for fish is made with the aid of underwater television, echo rangers and by direct visual observations. Next, four surface vessels, one mothership and three smaller ones, following directions from the undersea craft, approach from the edges of the area, towing sound vibrators which herd or drive fish towards the center of the circle.

Slowly, these vessels converge reducing the circle of sound until fish are concentrated within a radius of a half mile. One vessel is then detached from the others, which continue to hold the sound barrier, and an electric cable and chemical dispensing hose are placed around the group of fish. This will then be drawn in, concentrating them into a circle of a few hundred yards, using traces of chemical solutions and visual dyes to tighten the web of control.

Next an electric current pulls the school tight and raises it to large pumps where it is drawn aboard the mothership.

With suitable manipulation of the electric current the catch is sorted by size —perhaps even by species—as fish are pumped aboard. Those which are destined for filleting could be drawn aboard first, those for reduction to meal and oil later.

Next, conveyor belts carry the food fish through filleting machines, after which they are packaged and frozen or preserved by atomic radiation. The fish are processed in prime condition in less than an hour after being taken from the sea. This whole operation, resulting in the catch of all fish of the desired species and size in a five-mile area, has required about two hours.

Georges Bank, or a similar vast area of the sea, is fished with a few specialized vessels during ideal conditions of season and weather. Fishermen work in heated or air-conditioned compartments instead of handling fish in freezing weather or under the hot sun.

This highly efficient method of fishing, admittedly rather imaginative in terms of today's knowledge, can be achieved provided we learn enough about the sea and the fish in it. It presupposes that we know as much about animals in the sea as the farmer does about those on land. We must know: (1), how many fish of all kinds are in the sea, (2), how they are distributed, (3), what factors control their abundance, (4), how they respond to various stimuli, (5), how they can be caught at the right time in their life to ensure maximum production and (6), how many to spare so that future production is assured. The last item is very important. For each species, we must know the maximum rate at which fish may be caught and still assure future production, for with such efficient methods of fishing it would be easy to reduce abundance quickly and endanger spawning stocks. Thus knowledge derived through oceanography can lead the way to wise fishing practices, better working conditions, and reduce production time and costs.

Besides revolutionizing our methods for harvesting the open sea, new research can lead to development of other ways of producing fishery products, for example, farming the edge of the sea, growing shrimp, crabs, oysters, clams and fish in ponds or portions of estuaries. Under such controlled conditions, more desirable products could be developed through selective breeding, predators could be controlled, the environment manipulated, and the animals fed on highly nutritive diets for rapid growth. Fish and shellfish could be grown to market size in a few months. The fishing industry might become known for "Beltsville" shrimp or Black Angus oysters as agriculture has become famous for certain strains of turkeys and cattle.

A realization of the need for the United States to gain more from the oceans, through increased resource production, improved transportation, better understanding of climate, and greater protection against military attack, led the National Academy of Sciences to examine the Nation's needs for oceanographic research. The Committee, organized in 1957, made a survey of the present status of the marine sciences in the United States. Its report, "Oceanography 1960-1970," (National Academy of Sciences—National Research Council 1959) contains recommendations which can strengthen marine sciences and, among other things, lead to greater development and utilization of ocean resources.

The Committee found that relative to other scientific endeavors progress in marine science has been slow. Research undertaken in the past has been done under difficult circumstances, handicapped by insufficient manpower, ships, and shore facilities. In the field of ocean resources, this has prevented an adequate understanding of the occurrence, behavior and potential harvest of fish and many other marine organisms. This lack of understanding is a serious barrier to their full economic development and utilization.

The Committee has, therefore, recommended that research on fishery resources be expanded over the next ten years. New information should be produced which will help fishermen improve methods of harvesting. Research on fish behavior, physiology, response to stimuli, and genetics of marine animals has been stressed. New knowledge gained about the oceans and its life can lead to new ways of fishing and of growing fish and shellfish even more startling than those described here.

Research and surveys have been recommended which will define potential yields of latent fisheries and reduce fishing costs by predicting times and places where fish concentrate. It may even be possible to modify the marine environment and thus improve fish survival and smooth-out abundance fluctuations.

It is easy to foresee that, in time, wide expanses of the open ocean and many coastal areas will be fished or farmed to increase our protein supply. Many species, not now utilized, will be brought to market. There will be need for radical changes in methods of fishing and in our concepts about use of products from the sea. The National Academy of Sciences has told scientists, Government, and the fishing industry what must be done to accomplish this goal. The gains can be substantial but only after long-term, painstaking research, which should be started without delay if we are to compete with other countries or even maintain our present position among the fishing nations.

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Age and Growth of the Whitefish, *Coregonus clupeaformis*, of Munising Bay, Lake Superior[1]

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ABSTRACT

This study is based on a sample of 415 whitefish collected in 1953 from an unexploited population in Munising Bay, Lake Superior. Gill-net and trawl catches had different length-frequency distributions and age compositions, but estimates of growth from the two catches were very similar. The body-scale relation is a straight line with an intercept of 1.5 inches. Weight of Munising Bay whitefish captured in June increased as the 3.17 power of the length. Growth in length and weight of Munising Bay whitefish was the slowest yet reported from Great Lakes waters. Munising Bay whitefish required nearly 8 years to reach a length of 10 inches and a full 13 years to reach 15 inches. Slightly more than 8 years were required to reach a weight of 8 ounces and a little less than 14 years to reach 1 pound. The sex ratio of the Munising Bay whitefish exhibited no systematic change with an increase in age. The entire sample for which ages were determined contained 52 percent males. Munising Bay whitefish matured at much shorter lengths but at a greater age than reported for other Great Lakes whitefish populations. The smallest mature males were in the 11.5- to 11.9-inch length interval (age-group VII) and all males longer than 14.4 inches (age-group XII) were mature. The first mature females appeared at 12.0-12.4 inches (age-group X) and all females longer than 14.9 inches (age-group XII) were mature. The more rapidly growing individuals matured earlier than the slow-growing ones.

INTRODUCTION

The present paper is a contribution to a continuing study of the U. S. Bureau of Commercial Fisheries designed to determine the extent of the differences in growth rate among local populations of the whitefish, *Coregonus clupeaformis*, of Lake Superior.

The Munising Bay (Figure 1) whitefish population is of special interest because it is unexploited and has an extremely slow growth rate. Lack of exploitation is attributable both to statutes which prohibit commercial fishing in Munising Bay and to the slow growth of individual fish, which prevents migrants from contributing materially to the commercial whitefish fishery immediately outside the bay. No explanation for the slow growth rate can be offered as a result of this study. The Munising Bay whitefish population, however, is apparently much denser than other Lake Superior whitefish populations, because fishing records for the Bureau's vessel *Cisco* indicate that many more whitefish were caught per unit of effort in Munising Bay than elsewhere in Lake Superior. Munising Bay whitefish are also most abundant at greater depths (22-38 fathoms) than are ordinarily frequented by Great Lakes whitefish. The temperatures at these depths are very low; the maximum of 45° F. is reached in late September.[2]

MATERIALS AND METHODS

Data from the 415 whitefish collected in Munising Bay in June and August 1953 dur-

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[1] This study was submitted as a master's thesis in the Department of Fisheries, University of Michigan.

[2] Temperature data taken during the 1953 and 1959 operations of the U. S. Bureau of Commercial Fisheries vessel *Cisco*.

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TABLE 1.—*Collections of Munising Bay whitefish, 1953*

Gear	Date of capture							Total
	June 17	June 18	June 21	June 22	August 14	August 15	August 16	
Trawl	82	38	5	0	0	—	—	125
Gill net	91	—	—	163	27	8	1	290
Total	173	38	5	163	27	8	1	415

ing the operations of the U. S. Bureau of Commercial Fisheries vessel *Cisco* are the basis for this study (Table 1). Information on length, weight, sex, and state of maturity was recorded for each fish. Scales were taken from 252 fish (all but the 163 fish captured on June 22).

All whitefish were caught by nylon gill nets and otter trawls. Individual gill nets were 250 feet long and 6 feet deep; each net was one in a series of eight mesh sizes ranging from 1 to 4½ inches.[3] Gill nets were fished in gangs with each gang consisting of a group of gill nets of different mesh sizes joined end to end. Gangs were set on the bottom, usually across the contours and left overnight. The trawls were 35 feet wide at the wings and 36 feet long with mesh sizes from 1½ to 2½ inches in the wings and body and ½ inch in the cod ends. Trawl tows were made on the bottom, generally along the contours, and usually lasted 10 minutes.

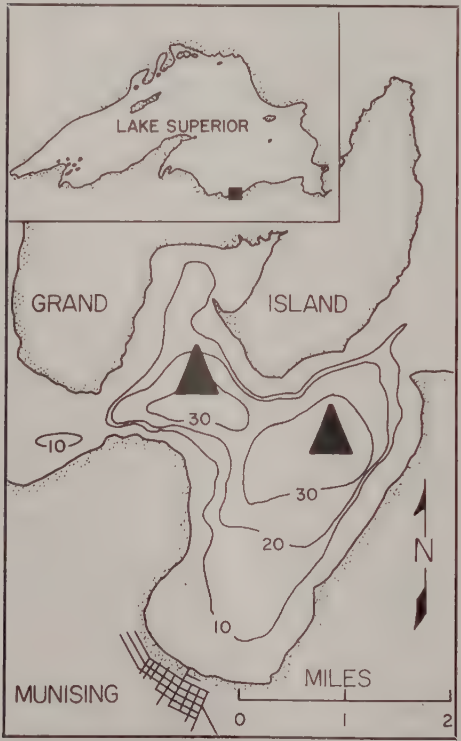

FIGURE 1.—Munising Bay, Lake Superior. Fishing locations shown by shaded triangles; depth contours are in fathoms.

Length distributions of fish in the June trawl and gill-net catches (Table 2) differ substantially. The trawl sample has a single strong mode in the 11.0- to 11.4-inch length interval, while the length-frequency distribution in the gill-net sample is skewed to the left and lacks the strong mode of the trawl sample at 11.0 to 11.4 inches. The average total lengths of fish in the June trawl and gill-net samples were 11.6 and 12.1 inches, respectively. Growth estimates of fish in catches from the two gears were closely similar, but estimates of age composition differed. A brief discussion of the significance of the difference

TABLE 2.—*Length distribution of Munising Bay whitefish caught by gill nets and trawls*

Length interval (inches)	Trawl		Gill net	
	Number	Percentage	Number	Percentage
7.0- 7.4	2	1.6	—	—
7.5- 7.9	1	0.8	—	—
8.0- 8.4	2	1.6	—	—
8.5- 8.9	3	2.4	—	—
9.0- 9.4	4	3.2	1	1.1
9.5- 9.9	10	8.0	3	3.3
10.0-10.4	12	9.6	8	8.8
10.5-10.9	11	8.8	13	14.3
11.0-11.4	21	16.8	11	12.1
11.5-11.9	9	7.2	9	9.9
12.0-12.4	12	9.6	12	13.2
12.5-12.9	11	8.8	11	12.1
13.0-13.4	7	5.6	9	9.9
13.5-13.9	5	4.0	4	4.4
14.0-14.4	7	5.6	3	3.3
14.5-14.9	2	1.6	1	1.1
15.0-15.4	3	2.4	2	2.2
15.5-15.9	2	1.6	1	1.1
16.0-16.4	1	0.8	—	—
16.5-16.9	—	—	2	2.2
17.0-17.4	—	—	1	1.1
Total	125	—	91	—
Average length	11.6	—	12.1	—

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[3] Mesh sizes are stretched-mesh measurements.

in length distributions of catches from gill nets and trawls with respect to age is presented in the section on age composition.

The total length (tip of the head to the tip of the tail, with lobes compressed) of each fish was read from a measuring board in the field and recorded to the nearest 0.1 inch. Fresh weights of the smaller whitefish were determined to the nearest 0.1 ounce on a spring scale with an 18-ounce capacity. Fish heavier than 18 ounces were weighed on a larger spring scale to the nearest full ounce. Scale samples were removed from the left side midway between the lateral line and the midpoint of the base of the dorsal fin and were placed in an envelope on which the length, weight, sex, state of gonads, date, gear, and location of capture were recorded.

The sex and state of maturity of the gonads were determined by gross examination. Mature fish were those judged to be ready to spawn in the fall of that same year. Impressions of the scales were made in cellulose acetate (Smith, 1954) and were magnified 43 diameters for study by means of a microprojector similar to that described by Moffett (1952). Measurements of scale diameters were made through the focus along the cephalo-caudal axis from the projected scale image as prescribed by Van Oosten (1923).

The ages of fish were determined from the annuli on their scales. Since each fish was considered to have passed into the next higher age group on January 1 a "virtual" annulus was accredited at the edge of the scale from January 1 to the date the current season's annulus actually was completed (Hile, 1948). Ages are expressed by Roman numerals corresponding to the number of annuli.

Annuli were characterized by a change in the spacing and thickness of the circuli in the anterior and lateral portions of the scale and by crossing over in the posterior-lateral portions. On many scales accessory marks and other odd patterns in the spacing and thickness of the circuli, especially near the margin, prevented age determination with reasonable accuracy. As a result, the scales of many whitefish (17.6 percent of the June catch) were discarded as unreadable.

The average total length of fish in the entire June sample was 11.8 inches, and the average total lengths of the aged and unaged portions of the sample were 11.6 and 12.9 inches, respectively. The greater average length of the unaged portion indicates that many of these fish were members of the older age groups. Although the records of age composition were biased by the rejection of numerous large fish, the calculated lengths gave no evidence of bias to growth estimates through the selective discarding of slow-growing individuals.

The 36 whitefish captured in August were excluded from age analysis because annulus formation was in progress at this time. This fact, and the great irregularity in the growth of individual fish, frequently made it impossible to decide whether marginal growth had been completed in the previous or the current season. Whitefish caught in June presented no such difficulty because growth had not yet started.

AGE COMPOSITION

The age composition of the trawl and gill-net samples (Table 3) differed both in relative strength of age groups and in average age. Age distributions of both trawl and gill-net samples were unimodal, but of the two the gill-net distribution was the more strongly dominated by a single age group. Age-groups II-XIII were represented in the trawl sample (age-group VI dominant — 19.0 percent) whereas age-groups IV-XVI were represented in the gill-net samples and age-group VII was strongly dominant (31.5 percent). The representation of whitefish in neighboring age groups fluctuated much more widely in the

TABLE 3.—*Age composition of the Munising Bay whitefish caught by gill nets and trawls*

Age group	Trawl		Gill net	
	Number	Percentage	Number	Percentage
II	2	1.9	—	—
III	5	4.8		
IV	11	10.5	6	8.2
V	14	13.3	5	6.8
VI	20	19.0	11	15.1
VII	14	13.3	23	31.5
VIII	13	12.4	9	12.3
IX	9	8.6	7	9.6
X	6	5.7	9	12.3
XI	6	5.7	1	1.4
XII	4	3.8		—
XIII	1	1.0	1	1.4
XVI	—	—	1	1.4
Total	105	—	73	—
Average number of annuli	6.9	—	7.4	—

gill-net sample and exhibited a less regular trend than in the trawl sample. The average age of fish in the gill-net samples (7.4 years) was 0.5 year greater than in trawl samples (6.9 years). The data of Table 3 do not appear to justify speculation as to the relative strength of the year classes. The differences between the age compositions of the trawl and gill-net samples, especially in view of the exceptionally slow growth rate of this population, are attributed to the differences in the length distributions of the two samples (Table 2).

Although the absence or scarcity of young whitefish in the gill-net sample can be attributed to the difficulty of holding very small fish in gill nets (Hile, 1941), their scarcity in the trawl sample can not. The ½-inch mesh of the cod ends of trawls used was certainly able to retain small whitefish. If small fish had been abundant, they should have been taken in good numbers even though some escaped through the mesh of the trawl body. The scarcity of young whitefish in the trawl sample therefore is believed to be a true reflection of the relative abundance of this segment of the population at the bottom on the deep-water fishing grounds. It is not known, however, whether the absence of young whitefish on the fishing grounds is indicative of a difference in habitat preference or of weak year classes in 1949-51. The decrease in the numbers of Munising Bay whitefish with an increase in age (age-groups VIII-XVI) is typical and undoubtedly reflects mortality.

LENGTH DISTRIBUTION OF THE AGE GROUPS

There is considerable range in the length of fish in the same age group (Table 4) and extensive overlap between neighboring age groups. Among the better represented age groups the greatest span between the longest and shortest individuals of the group was 3 to 4 inches. The better represented length intervals contained fish from four to seven age groups. The overlapping of the distributions was the result of the considerable range of lengths of most of the age groups in a stock in which the average annual increments of growth were relatively small. As a result, length alone is a poor index of age of Munising Bay whitefish.

LENGTH-WEIGHT RELATION

The general parabola, $W = cL^n$, where W = weight, L = total length, and c and n are empirically determined constants, has been used satisfactorily to describe the general length-weight relationship of the numerous species and stocks of fish. Determination of the length-weight relation of the Munising Bay whitefish was based on the data from the 379 fish captured in June and may not be ac-

TABLE 4.—*Length distribution of age groups of Munising Bay whitefish*

Length interval (inches)	Age group												
	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XVI
7.0- 7.4	1	1	—	—	—	—	—	—	—	—	—	—	—
7.5- 7.9	1	—	—	—	—	—	—	—	—	—	—	—	—
8.0- 8.4	—	1	—	—	—	—	—	—	—	—	—	—	—
8.5- 8.9	—	2	1	—	—	—	—	—	—	—	—	—	—
9.0- 9.4	—	1	2	—	1	—	—	—	—	—	—	—	—
9.5- 9.9	—	—	5	6	1	1	—	—	—	—	—	—	—
10.0-10.4	—	—	6	6	6	2	—	—	—	—	—	—	—
10.5-10.9	—	—	2	5	6	7	4	—	—	—	—	—	—
11.0-11.4	—	—	1	1	12	13	2	2	—	—	—	—	—
11.5-11.9	—	—	—	—	2	3	8	3	—	—	—	—	—
12.0-12.4	—	—	—	1	2	5	1	2	4	1	—	—	—
12.5-12.9	—	—	—	—	1	6	5	1	—	1	—	—	—
13.0-13.4	—	—	—	—	—	—	2	3	5	1	—	—	—
13.5-13.9	—	—	—	—	—	—	—	2	2	—	1	—	—
14.0-14.4	—	—	—	—	—	—	—	2	3	1	—	—	—
14.5-14.9	—	—	—	—	—	—	—	—	—	1	—	—	—
15.0-15.4	—	—	—	—	—	—	—	1	—	1	1	1	—
15.5-15.9	—	—	—	—	—	—	—	—	—	1	1	1	—
16.0-16.4	—	—	—	—	—	—	—	—	1	—	—	—	—
16.5-16.9	—	—	—	—	—	—	—	—	—	—	1	—	1
Number of fish......	2	5	17	19	31	37	22	16	15	7	4	2	1
Percentage of total...	1.1	2.8	9.6	10.7	17.4	20.8	12.4	9.0	8.4	3.9	2.2	1.1	0.6
Average length....	7.4	8.5	9.9	10.4	11.0	11.4	11.9	12.8	13.4	14.0	15.5	15.6	16.7

curately descriptive for other times of the year. Whitefish collected in August were heavier than fish of the same length that were captured in June but there were too few August specimens to establish clearly the extent of the seasonal fluctuation. The length-weight equation, determined by fitting a straight line to the logarithms of the lengths and weights listed in Table 5, was:

$$\log W = 2.5596 + 3.1712 \log L,$$

where W = weight in ounces and L = total length in inches. This equation may also be written in the form,

$$W = 7.4788 \times 10^{-3} L^{3.1712}.$$

Table 5.—*Length-weight relationship of Munising Bay whitefish*

[The lengths are the true averages for fish in 0.5-inch groups]

Number of fish	Average total length (inches)	Average weight (ounces)	
		Empirical	Calculated
2	7.3	1.4	1.5
1	7.5	1.6	1.6
2	8.2	2.1	2.2
3	8.8	2.8	2.7
5	9.2	3.1	3.1
14	9.7	3.6	3.7
25	10.2	4.2	4.4
36	10.7	5.1	5.1
56	11.2	6.1	5.9
38	11.7	6.9	6.7
55	12.3	7.8	7.9
40	12.7	8.9	8.9
35	13.2	10.2	9.9
28	13.7	11.4	11.1
16	14.3	12.4	12.7
7	14.7	14.1	13.9
8	15.2	16.3	15.4
4	15.7	16.7	17.1
1	16.4	16.1	19.6
2	16.8	20.8	21.2
1	17.4	26.8	23.7

The value of n indicates that weight increases more rapidly than the cube of the length.

The data of Table 5 indicate a generally good agreement between empirical and calculated weights. The largest discrepancies were at the greater lengths where numbers of fish were small and actual weights great enough to make relatively modest percentage disagreements seem larger.

The weight of whitefish caught in June varies according to maturity and sex (Table 6). Weights of immature male and female fish of the same length did not differ significantly. The mature fish, however, were usually heavier than immature fish, and the mature females were generally heavier than the mature males.

Table 6.—*Weight (ounces) of Munising Bay whitefish by sex and maturity*

[Number of fish in parentheses. Fish shorter than 11.5 inches were immature. Sex and maturity data missing for one fish 14.2 inches long]

Total length (inches)	Male		Female	
	Immature	Mature	Immature	Mature
11.5-11.9	6.6 (12)	7.3 (5)	6.9 (19)	6.5 (2)
12.0-12.4	7.7 (23)	8.0 (7)	7.6 (18)	8.4 (7)
12.5-12.9	8.7 (17)	9.2 (7)	8.9 (15)	9.9 (1)
13.0-13.4	9.7 (9)	10.3 (9)	10.3 (14)	11.0 (3)
13.5-13.9	11.3 (9)	11.4 (7)	11.2 (7)	11.8 (5)
14.0-14.4	— —	12.1 (7)	12.5 (5)	12.8 (3)
14.5-14.9	— —	13.6 (2)	13.8 (3)	15.2 (2)
15.0-15.4	— —	16.3 (5)	— —	16.3 (3)
15.5-15.9	— —	18.8 (1)	— —	16.0 (3)
16.0-16.4	— —	16.1 (1)	— —	— —
16.5-16.9	— —	20.8 (2)	— —	— —
17.0-17.4	— —	— —	— —	26.8 (1)
Number of fish	70	53	81	30

BODY-SCALE RELATIONSHIP

Van Oosten (1923) demonstrated that the ratio of the diameter of the scales of Lake Huron whitefish to the length of fish was nearly constant. A similar body-scale relationship has been demonstrated for the related lake herring *(Coregonus artedi)* by Van Oosten (1929) and by Smith (1956). Largely on the basis of Van Oosten's findings (1923, 1929) most investigators working on coregonids have employed the direct-proportion method for the calculation of growth. The body-scale relationship was, nevertheless, determined for the Munising Bay whitefish stock. "Key" scales were not available, but because the scale samples were taken from a key area, it was felt that average scale diameters based on the measurements of three (sometimes two) scales from each fish would be a reliable substitute for key-scale measurements in the determination of body-scale relationship.

All whitefish captured in June and August, from which scales were collected, were employed for the determination of the body-scale relationship (Table 7). Since a plot of average fish length and scale diameters for 0.5-inch groupings of fish indicated the body-scale relation to be linear, a straight line was fitted to the data by least squares (Figure 2). The equation of the line is:

$$L = 1.486 + 1.222\,S,$$

where L = the total length of the fish (inches), S = the scale diameter (magnified) in inches, and 1.486 is the intercept. Since this value of the intercept differs significantly from zero, it is concluded that the body-scale ratio is not constant in the Munising Bay whitefish population.

The growth in length of the whitefish was calculated by the formula

$$L_n = 1.5 + \frac{L_t - 1.5}{S_t} S_n$$

where L_n equals the length of the fish at the end of the n^{th} year of life, S_n equals the diameter of the scale within the n^{th} annulus, L_t equals the total length of the fish at capture, S_t equals the total diameter of the scale, and 1.5 is the intercept rounded to the nearest 0.1 inch.

CALCULATED GROWTH IN LENGTH

The average calculated lengths of males and females in different age groups of whitefish gave no evidence of sex differences in the growth rate. Data for males and females therefore were combined (Table 8). The agreement among the calculated growth histories of the different age groups was very close, particularly in view of the small number of fish in several groups and the great difficulty with which the scales were read. No clear trends are to be seen toward a systematic change of calculated lengths with increase of age, and discrepancies that do occur probably can be attributed to small samples or annual fluctuations of growth. Especially reassuring is the agreement between length at capture (the last length for each age group) and the calculated lengths for the same year of life as determined by measurements of scales of fish of greater age. The data of Table 8 appear to justify fully the conclusions that (1) the samples of the age groups were little biased by gear selection or other selective influence, (2) estimates of growth were little affected by the rejection of numerous fish that had unreadable scales, and (3) the empirically determined body-scale relation was highly satisfactory for the calculation of growth.

TABLE 7.—*Relation between total length of fish and magnified scale diameter of Munising Bay whitefish*

[Scales were taken from a key area; scale diameter in inches x 43]

Length interval (inches)	Number of fish	Average length (inches)	Average magnified scale diameter
7.0- 7.4	2	7.3	4.5
7.5- 7.9	1	7.5	5.9
8.0- 8.4	2	8.1	4.7
8.5- 8.9	3	8.8	6.1
9.0- 9.4	8	9.3	6.7
9.5- 9.9	17	9.7	6.8
10.0-10.4	27	10.2	7.2
10.5-10.9	28	10.7	7.2
11.0-11.4	37	11.2	8.0
11.5-11.9	23	11.7	8.2
12.0-12.4	24	12.3	8.8
12.5-12.9	28	12.6	9.0
13.0-13.4	16	13.2	9.3
13.5-13.9	10	13.7	9.9
14.0-14.4	11	14.2	10.3
14.5-14.9	3	14.6	10.9
15.0-15.4	5	15.3	11.2
15.5-15.9	3	15.7	11.7
16.0-16.4	1	16.4	12.0
16.5-16.9	2	16.8	12.5
17.0-17.4	1	17.4	13.0

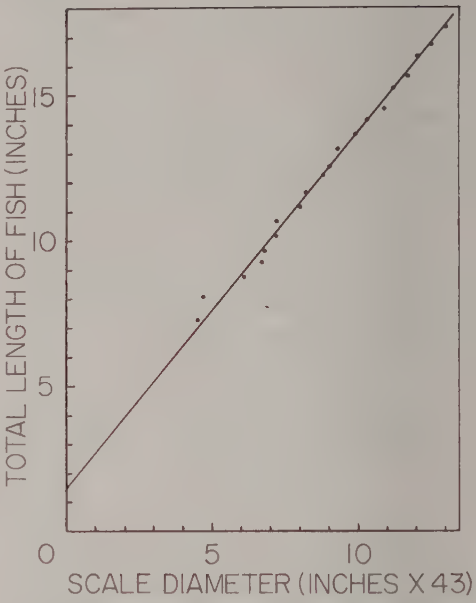

FIGURE 2.—Relation between total length of fish and magnified diameter of scales of Munising Bay whitefish.

The estimates of the general growth in length at the bottom of Table 8 are based on the grand average calculated lengths and on the successive summation of the grand average increments of calculated length. Both procedures are basically valid and for the Munising Bay fish they give closely similar

TABLE 8.—*Calculated total length at end of each year of life of each age group of Munising Bay whitefish and average growth for the combined age groups*

[The last calculated length for each age group is actually the average length at capture in June, as the current season's growth had not begun]

Age group	Number of fish	Length (inches) at end of year															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
II	2	4.5	7.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
III	5	5.6	7.2	8.5	—	—	—	—	—	—	—	—	—	—	—	—	—
IV	17	5.5	7.5	8.7	9.9	—	—	—	—	—	—	—	—	—	—	—	—
V	19	5.5	7.1	8.7	9.7	10.4	—	—	—	—	—	—	—	—	—	—	—
VI	31	5.5	7.3	8.5	9.4	10.2	11.0	—	—	—	—	—	—	—	—	—	—
VII	37	5.7	7.5	8.7	9.5	10.2	10.9	11.4	—	—	—	—	—	—	—	—	—
VIII	22	5.5	7.1	8.2	9.2	10.0	10.7	11.3	11.9	—	—	—	—	—	—	—	—
IX	16	5.5	7.1	8.2	9.2	10.0	10.9	11.6	12.2	12.8	—	—	—	—	—	—	—
X	15	5.2	6.7	7.9	8.9	9.8	10.6	11.3	12.0	12.7	13.4	—	—	—	—	—	—
XI	7	5.0	6.8	8.1	9.1	9.9	10.7	11.6	12.3	12.9	13.4	14.0	—	—	—	—	—
XII	4	5.4	6.7	8.2	9.0	9.9	10.9	12.0	13.0	13.7	14.4	15.0	15.5	—	—	—	—
XIII	2	5.4	6.9	8.4	9.5	10.4	11.6	12.3	12.9	13.6	14.3	14.9	15.4	15.8	—	—	—
XVI	1	5.0	6.3	7.9	8.8	9.6	10.2	11.1	12.0	12.6	13.2	14.5	15.2	15.5	16.0	16.3	16.7
Grand average calculated length		5.5	7.2	8.4	9.4	10.1	10.8	11.5	12.1	12.9	13.6	14.4	15.4	15.7	16.0	16.3	16.7
Increment of average		5.5	1.7	1.2	1.0	0.7	0.7	0.7	0.6	0.8	0.7	0.8	1.0	0.3	0.3	0.3	0.4
Grand average increment of length		5.5	1.7	1.2	1.0	0.8	0.8	0.7	0.6	0.6	0.6	0.7	0.5	0.3	0.5	0.3	0.4
Sum of average increment		5.5	7.2	8.4	9.4	10.2	11.0	11.7	12.3	12.9	13.5	14.2	14.7	15.0	15.5	15.8	16.2

results. The estimate based on the sum of the average increments, however, is preferred (Figure 3). The curve derived from average increments has the advantage of greater smoothness, particularly in the later years of life that are represented by few fish.

The growth of Munising Bay whitefish is similar to that of many coregonids in that the annual increment was by a large margin the greatest in the first year of life and thereafter followed a general (though not perfectly regular) downward trend. The increments beyond the first year were very low. Second-year growth amounted to only 1.7 inches and no annual increment exceeded 1.0 inch after the third year or 0.5 inch after the eleventh. As a result of this slow growth, Munising Bay whitefish required almost 5 years to reach a length of 10 inches and a full 13 years to reach 15 inches. The highest calculated length attained (16.2 inches in 16 years) was still 0.8 inch below the Michigan legal minimum length of 17 inches. Exploitation of the Munising Bay stock under the present size limit would not be a rewarding operation.

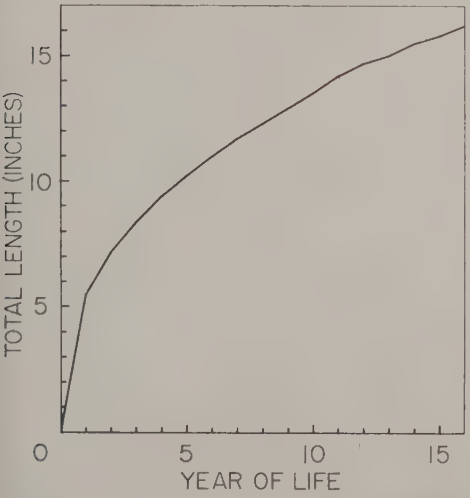

FIGURE 3.—General growth in length of Munising Bay whitefish.

CALCULATED GROWTH IN WEIGHT

Calculated growth in weight (Table 9) was determined by applying calculated

TABLE 9.—*Calculated weights at the end of each year of life of Munising Bay whitefish*

[Weights are from the general length-weight relation and correspond to lengths at the end of year of life on the general growth curve]

Year of life	Calculated weight	Increment	Year of life	Calculated weight	Increment
1	0.6	0.6	9	9.2	1.3
2	1.5	0.9	10	10.6	1.4
3	2.4	0.9	11	12.4	1.8
4	3.3	0.9	12	13.9	1.5
5	4.3	1.0	13	14.8	0.9
6	5.6	1.3	14	16.4	1.6
7	6.7	1.1	15	17.4	1.0
8	7.9	1.2	16	18.9	1.5

lengths (sum of the average increments of length) of Table 8 to the length-weight relation. The annual increments of weight increased irregularly through the first 11 or 12 years and thereafter fluctuated without trend. Increments in individual years of life were small (0.6 ounce in the first year of life to a maximum of 1.8 ounces in the 11th year of life). Because of this slow growth in weight, considerable time was required for the fish to reach even a moderate size. Slightly more than 8 years were needed for fish to reach a weight of 8 ounces and a little less than 14 years to reach 1 pound.

COMPARISON OF THE GROWTH OF WHITEFISH IN MUNISING BAY WITH GROWTH IN OTHER WATERS

In order to compare the growth of whitefish from a number of localities (Table 10), the data from various sources have been adapted to permit presentation in terms of total length in inches. A full coverage of published data has not been attempted. All available records for the Great Lakes have been included, but data for other waters have been limited to two inland lakes that have stocks with extremely slow growth.

Growth of the Munising Bay whitefish in the first year of life does not differ greatly from the first-year growth in the other Great Lakes whitefish populations, and the length at the end of 2 years was very similar in Munising Bay and in the Fox Islands area of Lake Michigan. In all other comparisons, however, the Munising Bay whitefish were decidedly shorter than fish of the same age in other Great Lakes stocks. In general, the differences increased with age. Munising Bay fish after 4 years were 2.6 to 8.7 inches shorter than whitefish in other Great Lakes waters and in 12 years were 8.8 to 11.2 inches shorter (Lake Michigan not represented at the higher age).

Whitefish from two small inland lakes, on the contrary, had growth rates similar to or below that of the Munising Bay stock. Whitefish from Trout Lake, Wisconsin, (Hile and Deason, 1934) were shorter than Munising Bay fish in the first 4 years of life, but were longer in the sixth and later years (fifth-year lengths were identical in the two stocks). Slowest growth yet reported for any population is that of a stock of dwarf whitefish discovered by Kennedy (1943) in Lake Opeongo. These dwarf whitefish (Opeongo also contains a stock with more rapid growth) reached a length of 6.0 inches in 5 years as compared with 10.1 inches in Munising Bay.

SEX RATIO

Although the sex ratio of the Munising Bay whitefish fluctuated widely among the age groups (Table 11), the belief that the data were without trend was supported by a statistical test. Much of the variation probably was a result of the small numbers of fish in several of the age groups. In the entire sample, all ages combined, the sexes were almost equally represented (52 percent males).

The failure of the sex ratio of Munising Bay whitefish to change systematically with

TABLE 10.—*Growth in length of whitefish in Munising Bay and in certain other waters*

[Sources of data: Lake Erie, Van Oosten and Hile (1949); Lake Huron, adapted from Van Oosten (1939); Lake Ontario, adapted from Hart (1931); Lake Michigan, Roelofs (1957); Lake Opeongo (dwarf race), adapted from Kennedy (1943); Trout Lake, adapted from Hile and Deason (1934)]

Area	Average calculated total length (inches) at end of year of life															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Great Lakes																
Lake Erie	6.9	12.7	16.1	18.1	19.6	20.7	21.4	22.1	22.8	23.2	23.7	24.2	24.6	25.0	25.3	25.6
Lake Huron[1]	5.0	8.9	12.3	16.1	19.2	21.4	22.9	23.9	24.8	25.3	25.9	26.6	—	—	—	—
Lake Michigan																
Big Bay de Noc	5.6	9.4	13.8	17.9	—	—	—	—	—	—	—	—	—	—	—	—
South Fox Island	4.3	7.0	9.9	13.2	—	—	—	—	—	—	—	—	—	—	—	—
Lake Ontario[1] [2]	—	—	9.4	12.0	15.4	17.9	19.1	20.4	21.0	22.3	—	25.8	—	—	—	—
Lake Superior																
Munising Bay	5.5	7.2	8.4	9.4	10.1	10.8	11.5	12.1	12.9	13.6	14.4	15.4	15.7	16.0	16.3	16.7
Small inland lakes																
Lake Opeongo[3]	4.4	5.3	5.6	5.8	6.0	—	—	—	—	—	—	—	—	—	—	—
Trout Lake[3]	3.8	5.5	7.1	8.5	9.7	10.8	11.9	12.9	14.3	15.0	15.7	16.2	16.8	17.2	—	—

[1] Lengths taken directly from a table in Van Oosten and Hile (1949). Methods of adaptation are described by them.
[2] Actual lengths at capture during growing season subsequent to indicated year.
[3] Standard lengths converted to total lengths by means of a factor determined by Hile and Deason (1934).

TABLE 11.—*Sex composition of age groups of Munising Bay whitefish*

Age group	Number of males	Number of females	Percentage males
II	2	—	100
III	—	5	0
IV	11	6	65
V	12	7	63
VI	15	16	48
VII	21	16	57
VIII	11	11	50
IX	6	10	38
X	8	7	53
XI	5	2	71
XII	1	3	25
XIII	—	2	0
XVI	1	—	100
Total	93	85	52

increase of age is in contrast to the findings in two other Great Lakes stocks. The percentage of male whitefish in samples from Lakes Huron (Van Oosten, 1939) and Erie (Van Oosten and Hile, 1949) decreased with an increase in age. A decision as to whether this disagreement between the Munising Bay whitefish and the Lake Huron and Lake Erie stocks represents true differences in the biological characteristics of the stocks is reserved because of problems of segregation, biased sampling, and (in exploited stocks) differential exploitation. Indeed the whole question of the accurate determination of the sex ratio and of factors that influence the ratio is too complex to be discussed in this paper. An excellent review of the matter may be found, however, in a recent paper by Alm (1959).

MATURITY

The June and August samples of Munising Bay whitefish exhibited such closely similar trends in the relation between length and maturity that the data for the two groups were combined (Table 12). All fish shorter than 11.5 inches were immature. The smallest mature males appeared in the 11.5- to 11.9-inch length interval. Fifty percent of the males were mature at 13.0-13.4 inches and all males (11 fish) longer than 14.4 inches were mature. The first mature females appeared at 12.0-12.4 inches, somewhat fewer than half were mature at 13.5-14.9 inches, and all fish longer than 14.9 inches (7 individuals) were mature. First maturity and 100-percent maturity of males occurred at lengths 0.5 inch shorter than in females.

Whitefish attain maturity at much shorter lengths in Munising Bay than in Lake Huron where Van Oosten (1939) reported first maturity for males at 17.8 inches and of females at 18.3 inches, and 100-percent maturity for males at 20.1 inches and females at 21.5 inches. First maturity was attained in Great Slave Lake at a small size (20 percent mature at an average fork length of 12.1 inches) but average length at 100-percent maturity was 18.0 inches (Kennedy, 1953). Smallest mature whitefish yet reported were from Lake Opeongo where Kennedy (1943) found that the first dwarf whitefish (both males and females) were mature at a standard length of 4.3-4.5 inches.

The slow growth of Munising Bay whitefish in later years of life caused the small differences between the sexes in length at attainment of maturity (Table 12) to become large when the comparison is on the basis of age (Table 13). No female younger than the X group was mature whereas 14 to 50 percent of the males were mature in age-groups VII-IX. All fish of both sexes were mature, however, in the XII age group and older.

The age at first attainment of maturity is much greater in Munising Bay whitefish than in Lake Huron, Lake Erie, and Great Slave Lake stocks. In Lakes Huron (Van Oosten, 1939) and Erie (Van Oosten and Hile, 1949) the first mature whitefish were found in age-groups III and II respectively. The Great

TABLE 12.—*Relation between length and sexual maturity of Munising Bay whitefish*

[All fish shorter than 11.5 inches were immature; all fish longer than 14.9 inches were mature

Length interval (inches)	Male			Female		
	Number immature	Number mature	Percentage mature	Number immature	Number mature	Percentage mature
11.5-11.9	15	5	25	21	—	0
12.0-12.4	25	6	19	23	4	15
12.5-12.9	20	8	29	15	2	12
13.0-13.4	9	9	50	14	4	22
13.5-13.9	9	9	50	7	5	42
14.0-14.4	1	7	88	5	3	38
14.5-14.9	—	2	100	3	2	40

TABLE 13.—*Relation between age and sexual maturity of Munising Bay whitefish*

[In parentheses, number of mature fish at left and immature at right; all fish younger than age-group VII were immature and all in age groups older than XI were mature]

Age group	Percentage mature	
	Males	Females
VII	14.3 (3-18)	0.0 (16-0)
VIII	27.3 (3-8)	0.0 (11-0)
IX	50.0 (3-3)	0.0 (10-0)
X	37.5 (5-3)	42.9 (4-3)
XI	60.0 (2-3)	50.0 (1-1)

Slave Lake whitefish (Kennedy, 1953) achieved first maturity in age-group IV. The dwarf whitefish from Lake Opeongo achieved first maturity in age-group II.

The more rapidly growing members of the Munising Bay whitefish stock mature earlier than the slow-growing individuals. The mature fish were longer in six of seven comparisons between the mean lengths of mature and immature fish of the same age and sex (Table 14); the X-group females were the single exception. This finding is in agreement with observations on the relation between growth rate and attainment of maturity in numerous populations (Alm, 1959).

TABLE 14.—*Relation between the average length of immature and mature Munising Bay whitefish of the same age*

[All fish in age-group VI and younger were immature; all fish in age-group XII and older were mature]

Age group	Male		Female	
	Immature	Mature	Immature	Mature
VII	11.5	12.5	—	—
VIII	11.8	12.3	—	—
IX	12.9	14.6	—	—
X	12.8	14.2	13.5	12.9
XI	12.5	14.0	14.2	15.5

ACKNOWLEDGMENTS

The crew of the M/V *Cisco* collected the field data on which this study is based. Stanford H. Smith and other members of the Ann Arbor Biological Laboratory, Bureau of Commercial Fisheries, U. S. Fish and Wildlife Service, gave advice during the preparation and examination of the data. Ralph Hile assisted in the preparation of the manuscript.

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Observations on the Behavior of the Porpoise Delphinus delphis

Abstract. Common porpoises have been observed in January, in the area of the Hudson Canyon, feeding on fish that escaped an otter trawl. An echo-sounder also recorded, in one instance, a descent of a porpoise to a depth of 200 feet in less than 2 minutes.

On the afternoon of 2 February 1959, we had an opportunity to observe two porpoises (*Delphinus delphis* Linnaeus) feeding on fish escaping from a trawl net, and to record them at depth on an Edo echo-sounder (Navy designation AN/UQN-1B; apex of sound beam about 30° between the half-power points). The observations were made aboard the R/V *Albatross III* (cruise 126, station 10-6, lat. 39°48′ N, long. 72°28′ W, depth of water 200 feet, surface temperature 45.9°F) in the area of the Hudson Canyon. At this season in these waters the observation of this species is, in itself, worthy of note.

Immediately following the haul back of the otter trawl, two porpoises appeared and began to feed on specimens of red hake (*Urophycis chuss* Walbaum) and scup (*Stenotomus versicolor* Mitchill) that had escaped from the net. These fish were disabled and were floating belly up as a result of their air bladders being decompressed. The porpoises were circling about at the surface and usually passed by each fish at least once before turning and picking it up.

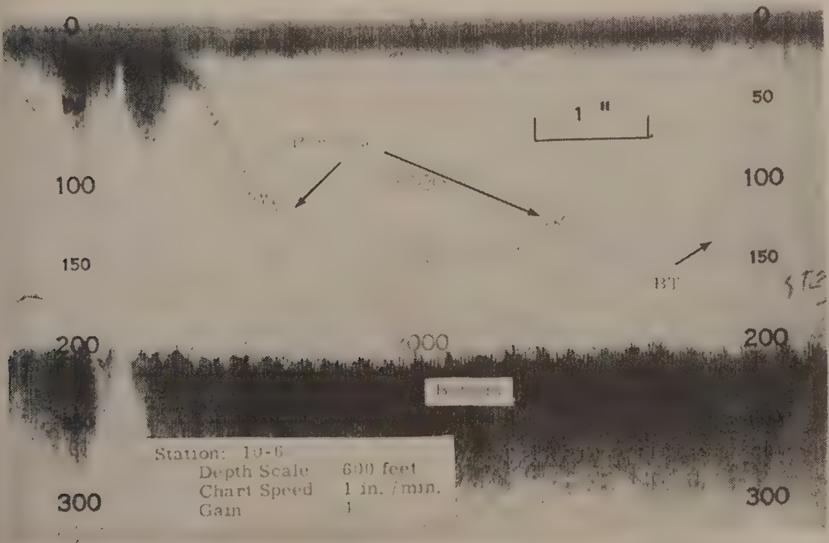

Fig. 1. Portion of echo-sounder chart showing echoes from common porpoises and from bathythermograph (BT). The vessel was hove to at the time this record was made.

The porpoises did not appear to be the least bit alarmed by the boat or the many people moving around on deck. They passed within a few feet of the boat several times.

Both porpoises disappeared for short intervals, at which times distinctive echo sounding records were obtained. These tracings are unique in our experience; we feel, without doubt, that they represent echoes from the porpoises (see Fig. 1). Both porpoises once descended together to the bottom, a depth of 200 feet, in about 2 minutes, and returned to the surface in less time than that. One of them dived to about 150 feet shortly thereafter and stayed at that general depth for a short period before returning to the surface.

It is not uncommon for either marine biologists or commercial fishermen to observe sharks feeding on fish that have escaped from trawl nets near the surface. To our knowledge, however, this is the first record of porpoises behaving similarly. Records of the depths to which porpoises descend are rare. Since porpoises presumably retain some air in their lungs when submerged, echoes of the same sort observed from fishes with sizable air bladders may be expected, in addition to echoes from the large surface area presented by a porpoise. Further observations with echo-sounders may add considerably to our knowledge of the depths to which these interesting mammals descend.

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THE EFFECT OF THREE DIFFERENT TYPES OF GROWTH CURVES ON ESTIMATES OF LARVAL FISH SURVIVAL

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The Effect of Three Different Types of Growth Curves on Estimates of Larval Fish Survival[1]

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It has been known for a long time that survival rates for young marine pelagic fishes are low. This can be inferred from the known high fecundities of the adults and the relatively small resultant year-classes. The reduction in populations, where measured, is of several orders of magnitude. Slight changes in the shape of larval survival curves for successive year-classes, however, may result in sizeable differences in the abundance of resulting year-classes accruing to the fishery.

The procedures for sampling larvae and estimating their abundance are described by SETTE (1943) and AHLSTROM (1954). Sea stations are occupied at regular intervals and plankton samples taken. The fish eggs and larvae are removed and counted. The larvae are also measured and the measurements grouped into size-classes. The counts are adjusted to a standard which is the number under 10 m^2 of sea surface. Standardized counts are weighted for the area and time period they are to represent. Growth statistics are used to convert the estimates of abundance by size-class into estimates of abundance by age-group, i.e., survival curves. The type of growth curve used materially affects the shape of the survival curve for a given set of weighted counts. The shape of the survival curve has bearing on HJORT's hypothesis (1914).

Three types of growth curves are considered in this study because the early growth of larval fish has not been adequately described. The inadequacy results from two causes. First, pelagic fish larvae, generally, have not been raised far beyond the yolk-sac stage in the laboratory. Second, field data of the type described by AHLSTROM (1954), NAKAI and HATTORI (1955), and SETTE (1943) are not adequate for critical determination of growth in these early stages. Until the difficulties and inadequacies of field and laboratory data are overcome, several types of growth should be considered.

This study is addressed to the problem: given a series of weighted counts by size-class, what is the effect of growth-rate on estimates of survival? The

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sampling and weighting problems in obtaining the counts will not be discussed here. They have been discussed by SETTE and AHLSTROM (1948) and TAFT (in press).

Use of Growth Data and Behaviour of the Model

Population estimates P are made for eggs and successive size-classes of larvae. These P's give an abundance curve when plotted against the estimated average age of the size-class. If the P's for the various size-classes are given as a proportion of the P for eggs, a survival curve is obtained.

The population estimates are made representative of the average abundance of the size-class by adjusting for the length of time the larvae require to progress through each size-class (duration). This is done by dividing the weighted count by the duration, d:

$$P \text{ (size-class)} = \frac{\text{weighted count}}{d}$$

Growth-rate affects the curve in two ways: (1) it affects the size of P through its effect on d, and (2) it affects the average age of P, shifting it to the right or left on the survival plot.

The three types of growth curves to be considered are exponential: ($l = e^{kt}$); logarithmic: ($l = k \log t$); and arithmetic: ($l = kt$). These were chosen because: exponential growth has been used in the past, logarithmic growth has been indicated for yolk-sac and early post-larval stages in laboratory observations of FARRIS (see below) and arithmetic growth represents a possible intermediate type. In each case, the curves were fitted to two points, an intercept of 3 mm at 0 days and 10 mm at 25 days. These points represent reasonable approximations of sardine time-length relationships. The three growth curves then are:

Exponential: $\log \text{length (mm)} = \cdot477 + \cdot021\, t \text{ (days)}$
Logarithmic: $\text{length (mm)} = 3{\cdot}00 + 4{\cdot}98 \log t \text{ (days)}$[1]
Arithmetic: $\text{length (mm)} = 3{\cdot}00 + \cdot28\, t \text{ (days)}$

The three types of growth curves are shown in Figure 1. Their effect on d is shown in Table 1. When exponential growth is used, as has been done the estimation of survival curves below[2]), the d for early size-classes is large and the resultant P is small. On the other hand, for logarithmic growth, the d for early size-classes is small and the resultant P is large when compared to later size-classes. P for a constant weighted count is larger using the logarithmic growth model than it is using an exponential growth model.

In addition, if either exponential or logarithmic growth is used, the change in d becomes important in determining the final shape of the survival curve. Using the same growth-rate, d was calculated for different size-class intervals (Table 2). With exponential growth using equal size intervals, d becomes smaller as the fish get older; P for the older size-classes becoming larger. The shape of the curve may be determined more by the number of size-classes used in a

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[1] In the logarithmic growth curve, the addition of 1 to t defines the size at age 0 as 3 mm [$\text{length (mm)} = 3{\cdot}00 + 4{\cdot}95 \log (t + 1)$] and makes negligible differences in the length at subsequent sizes.

[2] Both SETTE (1943) and AHLSTROM (1954) use logarithmic transformations ($\log \text{length} = \log a + b \text{ age} \log e$) of the exponential growth function $\text{length} = ae^{b \text{ age}}$.

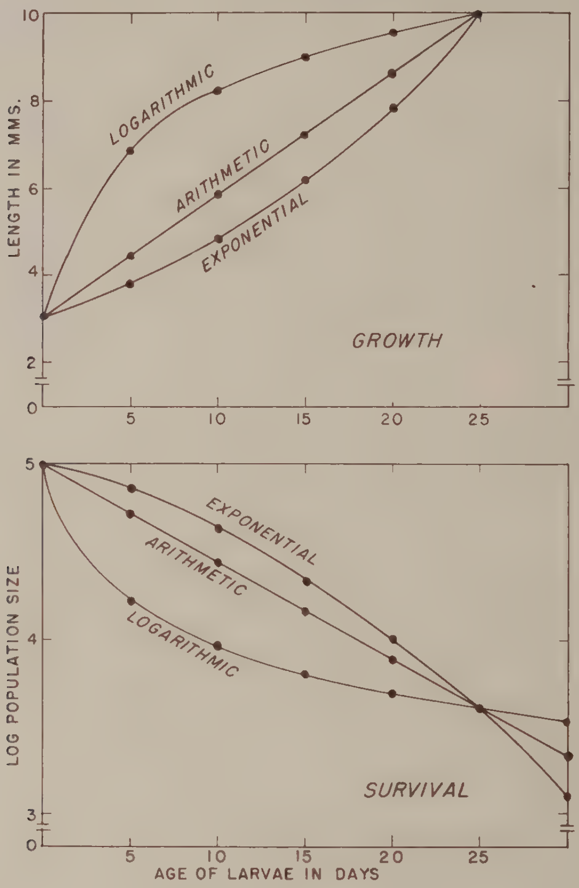

Figure 1 (Upper). Three types of growth curves.
(Lower). Model of larval fish survival hypothesizing three types of growth.
In computing age of larvae in days, hatching is time zero.

Table 1

The duration (*d*) of size-classes for three types of growth

Size range (mm)	Duration (*d*)			
	Exponential	Logarithmic Log *t*	Logarithmic Log (*t* + 1)	Arithmetic
3–4	5·9	·9	·6	3·6
4–5	4·6	1·5	·9	3·6
5–6	3·7	2·4	1·5	3·6
6–7	3·2	3·7	2·4	3·6
7–8	2·8	5·9	3·8	3·6
8–9	2·4	9·4	6·1	3·6
9–10	2·2	15·0	9·7	3·6

Table 2

The effect on duration (d) of various size intervals of size-classes, using $\log l = 0{\cdot}477 + 0{\cdot}021\ t$

Short Interval Size range (mm)	d	Long Interval Size range (mm)	d
3·0 – 3·5	3·2	3 – 4	6
3·6 – 4·5	4·6	4 – 7·5	13
4·6 – 6·25	6·3	7·6–12·5	10·3
6·26– 8·75	6·9	12·6–17·5	6·8
8·76–12·5	7·3	17·6–22·5	5·1

given growth interval than by its weighted count. The effect on average age of the three types of growth curves may be illustrated by showing the effect on a constant size-estimated population relationship. The relationship used is:

$$\log P = C - 0{\cdot}2\ l$$

where P is the estimated population, C a constant, and l the average length of the larvae in the size-class. If an arbitrary population of 100,000 is chosen as the size of P at time zero, then C must be 5·6 since the length at hatching is 3·0 mm. Therefore, the expression used in this study is:

$$\log P = 5{\cdot}6 - 0{\cdot}2\ l$$

This particular relationship was chosen because it represents in a simplified and stylized form what is actually observed. Standard numbers of sardine larvae (AHLSTROM, 1952) were corrected for larvae passing through the net (net selection) and larvae escaping the net (net avoidance) in making this assumption.

The relationships between size and age (i.e., growth curves) used earlier can be substituted into the above formula to give directly the relationship between estimated population size and age.

The new formulas are:

Exponential: $\log P = 5{\cdot}6 - 0{\cdot}2\ (3{\cdot}00\ e^{0{\cdot}048\ t})$
Logarithmic: $\log P = 5{\cdot}6 - 0{\cdot}2\ (3{\cdot}00 + 4{\cdot}98 \log t)$
Arithmetic: $\log P = 5{\cdot}6 - 0{\cdot}2\ (3{\cdot}00 + 0{\cdot}28\ t)$

The equations were then solved with values for t equal to 0[1]), 1, 5, 10, 15, 20, 25, and 30 days, and the average age plotted against P. The results are shown in Figure 1.

Survival in the exponential growth model diminishes at an increasing rate; diminishes at a decreasing rate in the logarithmic model; and decreases at a constant rate in the arithmetic model. In none of these models is there inconsistently a high rate of change per unit time.

It has been shown that if logarithmic growth is used, initial P values are smaller and the average age is less than if exponential growth is used. An attempt will be made to reconcile the growth models with measured growth-rates.

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[1]) See footnote (1), p. 295.

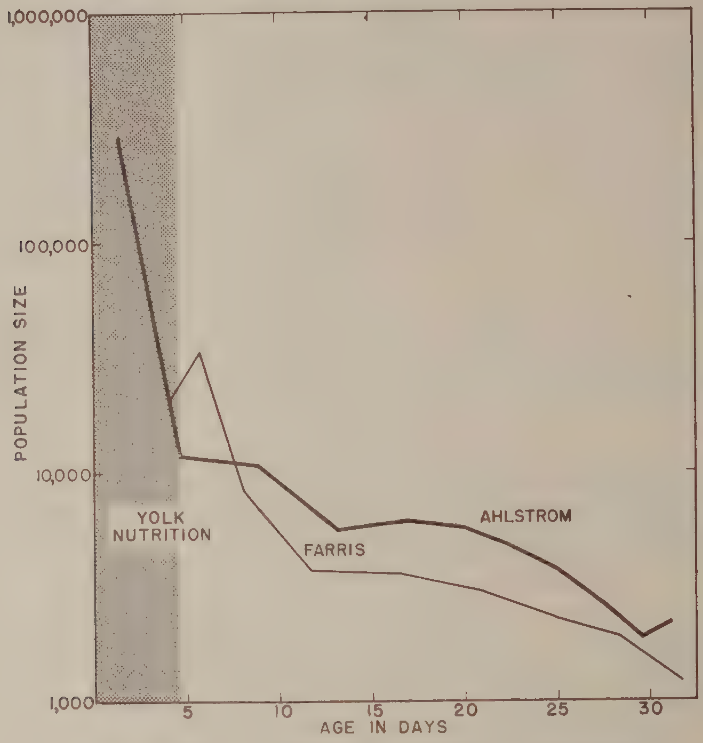

Figure 2. A comparison of estimates of larval sardine survival using exponential growth (after Ahlstrom) and a combination of logarithmic and exponential growth.

Growth-Rate of Larval Sardines

Sardine growth-rates have been measured by Ahlstrom (1954), Farris (1959), and Miller (1952). Farris has measured an initially high growth-rate (logarithmic) which he divided into two phases A and B. (The fish were not fed during the course of this experiment because it is believed that in nature, sardine larvae do not begin to feed until the yolk is absorbed. If this is not true, the growth-rate will be depressed due to starvation.)

The slope of the B phase is in good agreement with the growth-rate suggested by Ahlstrom. Ahlstrom's (1954, pp. 130–32) growth-rate for older larvae was derived from the use of length-frequency graphs.

The growth-rate through the yolk-sac stage given by Ahlstrom was obtained by measuring formalin preserved specimens of larvae that had been hatched and preserved at known time intervals. The difference between the Ahlstrom and Farris growth curves may be due to the shrinkage of the formalin preserved specimens used by Ahlstrom. Miller's data on yolk-sac larvae also show a high initial growth-rate. Miller [personal communication] has re-examined his material and agrees that the sardine larvae show an initial high growth-rate which decreases with time. It is therefore suggested that the early growth-rate of larval sardines may be approximated by an initial logarithmic growth curve and a subsequent exponential growth curve1).

The logarithmic growth expression described above was used in computing abundance of size-classes through 5·75 mm and the exponential growth expression for all succeeding size-classes. Using Ahlstrom's weighted counts, a new abundance curve was calculated (Figure 2). This curve differs from Ahlstrom's in that the yolk-sac-larvae-class now appears to be undersampled (as he suggested) when compared with the abundance of the next size-class. The estimated initial mortality, though high, is not as high as that computed by Ahlstrom. However, either estimate indicates better survival after yolk-sac absorption. If, on the other hand, the data are adjusted for net selection (using the tentative adjustment factors and the new growth functions), a period of high mortality is indicated after yolk-sac absorption.

Discussion

The question as to whether survival is better or worse after the transition from the yolk-sac stage is of special interest to students of Hjort's "critical period"2) hypothesis. Johan Hjort (1914, pp. 203–05) speculated that differences in annual survival which resulted in year-classes of varying strengths occurred during "the very earliest larval and young-fry stages." More specifically, "It may well be imagined, for instance, that a certain — though possibly brief — lapse of time might occur between the period when young larvae first require extraneous nourishment (i.e., yolk-sac absorption)3), and the period when such nourishment is available." Hjort's model is illustrated in Figure 3, showing the survival curve inflected downward at the time of yolk-sac absorption indicating an increased mortality at this time.

No attempt will be made to connect variation in larval survival with the relative size of the resultant year-class since data of sufficient reliability are not yet available. The assumption is made that the most likely source of variation in year-class size is the highest mortality whenever it occurs.

The following field data may be examined to determine whether survival is decreased following yolk-sac absorption. Sette's (1943) survival curve for Atlantic mackerel (Figure 4) shows constant survival through the period of yolk-sac absorption. Ahlstrom (1954) indicated a period of initial low survival followed by a period of better survival for Pacific sardines (Figure 5). A similar picture was given by Nakai and Hattori (1955) for Japanese sardines and anchovies (Figures 6 and 7). Three years of survival data were given by Farris (in press) for jack mackerel (Figure 8). This species also has a low initial survival followed by a period of better survival.

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1) Taft (personal communication) has fitted larval sardine growth data to a self inhibiting growth function $l_t = L - Ce^{-kt}$ where L is the ultimate length attainable on yolk material, C is a statistical constant to allow for the fact that the fish have finite length at time zero or hatching, k is the growth constant per unit growth yet to be made, and t is time in days.

2) The "critical period" in this paper refers to that very brief portion of a fish's life when it has a reduced chance of survival which, when held in common with other members of the specific population, governs the size of the ensuing year-class.

3) Phrase inserted by author.

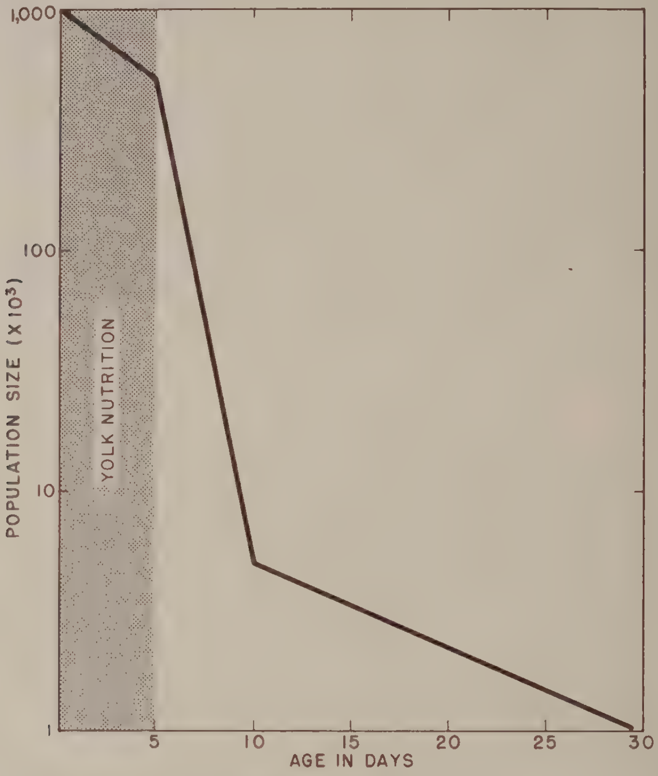

Figure 3. HJORT's model.

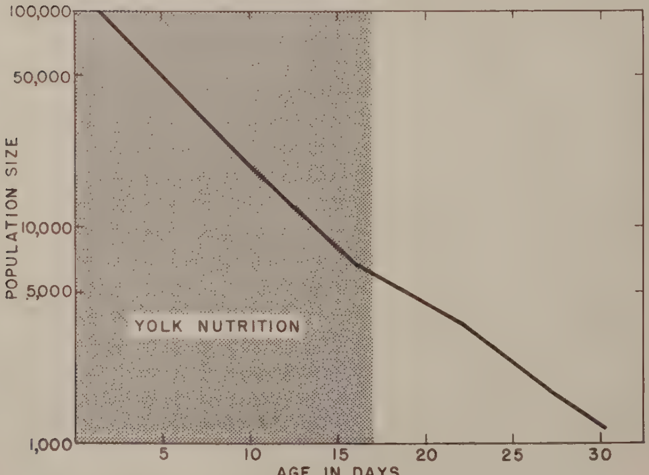

Figure 4. Survival of Atlantic mackerel (SETTE, 1943).

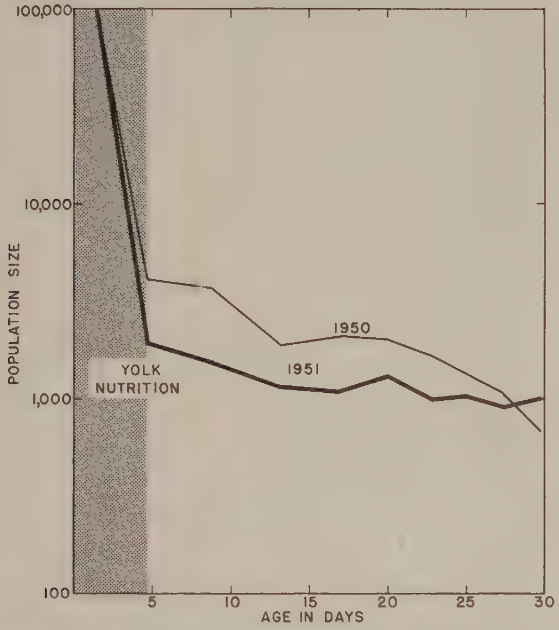

Figure 5. Survival of Pacific sardine (Ahlstrom, 1954).

These field data, with the exception of Atlantic mackerel, indicate that the onset of heavier mortalities occurs during the period when the larvae are living on their yolk and not after yolk-sac absorption as suggested by Hjort. Ahlstrom (1954, pp. 56–72) attributed the low estimate of early survival of sardines to incomplete retention of the small larvae by the sampling net. Marr (1956, p. 166) in his comprehensive discussion of the "critical period" was also of this opinion. If tentative net selection correction factors (supplied by Ahlstrom, personal communication) are applied to the population estimates, the survival curve becomes more linear on a log plot as Ahlstrom and Marr suggest. Further studies of the effects of net selection of the sardine is being undertaken by this laboratory.

Farris (in press) showed that loss through the sampling net is probably not the cause of the low estimates of early survival in jack mackerel. Low early survival in jack mackerel appears to be a real phenomenon, but in the case of sardines and perhaps anchovies, a portion of the apparent low survival estimate is due to loss of the larvae through the sampling net.

Laboratory investigations have attempted to substantiate the supposition that highest mortalities occur during or shortly after yolk-sac absorption. Fabre-Domergue and Bietrix (1897) noted that marine fish larvae die at greater rates after the yolk is used up. This "post-yolk sac mortality" has been noted by many others (Garstang, 1900; Marshall, Nicholls and Orr, 1937; Meyer, 1880; Orcutt, 1950; Rubinoff, 1958; Snow, 1959; and Yusa, 1958). These investigators did not give mortality data, so that the onset of increased

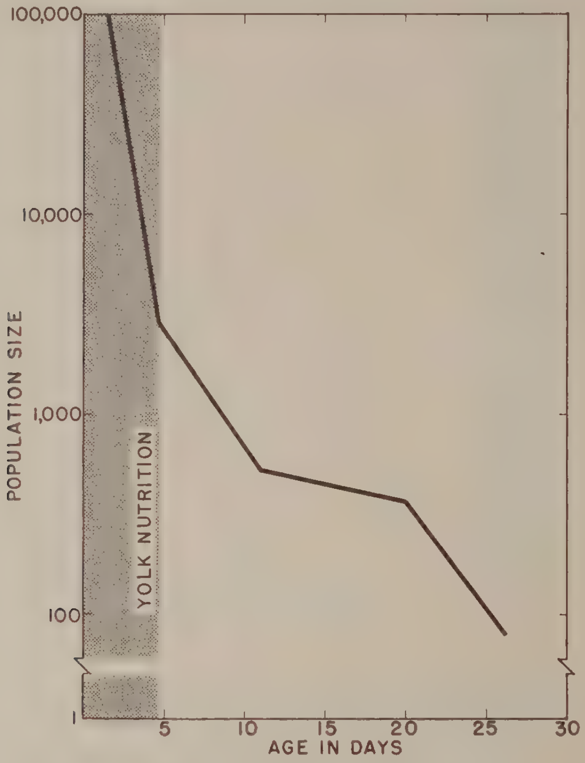

Figure 6. Survival of Japanese sardines (Nakai and Hattori, 1955).

mortality cannot be accurately determined. Because experimenters have been generally unsuccessful in getting larvae to feed, starvation has been assumed to be the cause of death. This point of view has been discussed by Morris (1956, p. 3), Rasquin (1958, p. 367), and Shelbourne (1957, pp. 350–51). On the other hand, a mortality curve (Figure 9) for laboratory-raised sardine larvae indicates that high mortality starts before complete yolk-sac absorption. Since the prime purpose of the previously cited investigations was not the estimation of larval fish mortality rates, the onset of high mortalities may have been misjudged. If the above statements are taken at face value, the Hjort hypothesis would appear to be demonstrated. However, a contradiction exists in that measurement of natural mortalities in the sea seems to indicate higher survival after yolk-sac absorption.

This discrepancy may be explained in several ways. Low survival prior to yolk-sac absorption in the sea may be due to predation, disease, bacterial action, or other environmental factors. On the other hand, it may be due to intrinsic factors such as a high proportion of eggs being imperfect at the time

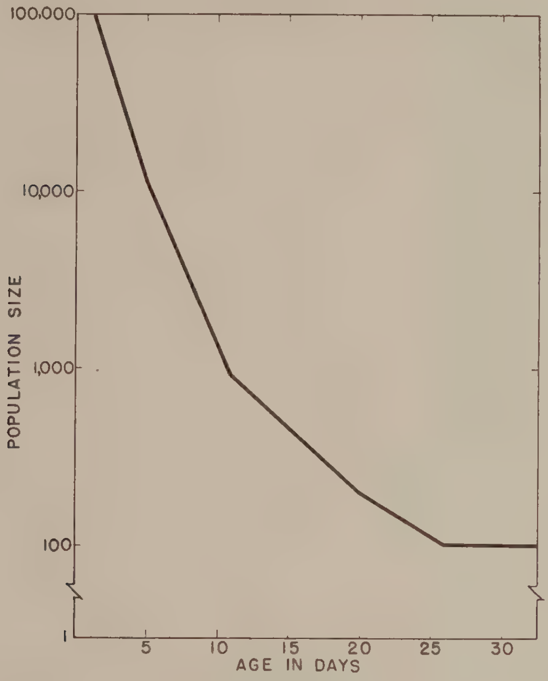

Figure 7. Survival of Japanese anchovies (NAKAI and HATTORI, 1955).

of spawning. If the latter supposition were true then the high mortalities (over 90%) occurring before yolk-sac absorption (as indicated by field studies) suggest that many eggs must be hatched in rearing experiments in order to observe a few larvae which have the proper kind and amount of yolk to pass through the "critical period". This may be the major reason that it is difficult to raise pelagic fish larvae in the laboratory. The above "natural" explanations may have no bearing on resolving discrepancies between laboratory and field studies.

HJORT's hypothesis may be restated in the form of three questions: (1) is there a brief period in the life of a year-class when survival is low (the "critical period")? (2) When does it occur? and (3) what is the controlling mechanism? My analysis of the available field data causes me to answer the first question with a tentative yes .... there is a "critical period" in jack mackerel. The effect of net selection, which needs more careful measurement for sardine survival estimates may indicate a "critical period" following yolk-sac absorption or may indicate a survival pattern similar to that of Atlantic mackerel, i. e., without a "critical period". But the published data indicate that the greater mortality occurs before or during yolk-sac absorption, not after. If the first two inferences are correct, then observations on "extraneous nourishment" (HJORT's phrase), will not lead to an understanding of the mechanism controlling the "critical period."

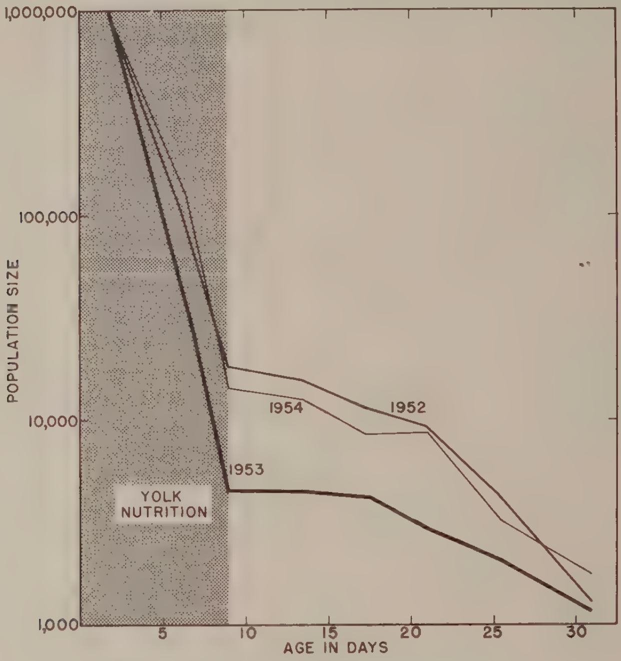

Figure 8. Survival of jack mackerel.

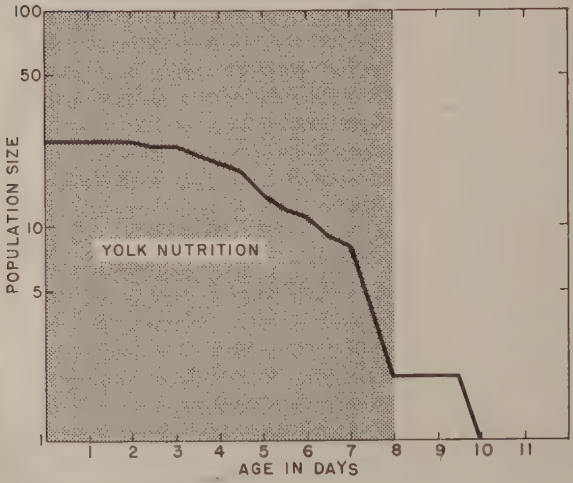

Figure 9. Survival of laboratory sardines. Yolk nutrition includes both the embryonic and yolk-sac larval periods.

Acknowledgements

I wish to thank Drs. E. H. AHLSTROM and O. E. SETTE, Mr. J. C. MARR and Mr. Bruce TAFT for their suggestions and critical reviews of this manuscript. The responsibility for the validity of the assumptions and the conclusions thereby derived must, of course, accrue to the author whose personal opinions, not necessarily held by the reviewers, are presented. The illustrations were prepared by Mr. George MATTSON, staff artist, Bureau of Commercial Fisheries, Biological Laboratory at La Jolla.

Summary

1. Of the many factors which affect estimates of larval fish survival, growth was selected for special study. Growth-rate determines the estimate of abundance of a size-class for a given weighted count, through its effect on the duration of the size-class. Growth-rate, also, affects the estimate of the average age of the size-class shifting the estimate laterally on the survival plot. Difficulties in rearing pelagic fish larvae past the yolk-sac stage in the laboratory and problems in obtaining adequate samples of larvae from the sea have prevented the accurate description of the growth of pelagic fish larvae.

2. Three different types of growth (exponential, logarithmic, arithmetic) were used in this study. The survival models resulting from the use of these do not show irregular changes in curvature of their survival curves which can be construed as indicative of critical periods. It is, therefore, believed that any change which occurs in a survival curve based on yearly abundance estimates by size-class must reflect conditions imposed on the estimate by the weighted counts of the size-classes.

3. Such growth data as are presently available for sardine larvae were applied to AHLSTROM's weighted counts of sardine larvae taken from the sea. The resultant survival curve indicates a high mortality before yolk-sac absorption if net selection is disregarded.

4. HJORT's "critical period" hypothesis suggested that increased mortality should occur after yolk-sac absorption. The field data presented do not support this contention. On the other hand, evidence from the laboratory observations reported in the literature indicate increased mortalities after yolk-sac absorption. Environmental factors present in the sea such as predation, but not present in the laboratory may account for the discrepancy. Alternatively, the non-quantitative way in which most previous laboratory observations have been reported, may have lent to confusion as to when the higher mortalities actually do occur.

5. A comparison of mortality rates of sardine larvae taken from the field (Figure 5) and laboratory (Figure 9) data do not appear to be in conflict. Both indicate that heavy mortality occurs before complete yolk-sac absorption. Therefore, survival may be governed by the yolk supplied by the spawning females which could vary from year to year depending on the age and diet of the spawning females.

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ANDELSBOGTRYKKERIET I ODENS

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p. 107

FAILURE OF AN ANCHOVY TO HATCH WITH CONTINUED GROWTH OF THE LARVA

Eggs and early larval stages of the anchovy, *Engraulis mordax* (Girard), are being investigated to determine hatching time with respect to temperature and rate of growth of early larvae. The study of larval growth rates was undertaken in order to determine the mechanism involved in the high mortality rates of larval marine fishes (See Sette 1943 and Ahlstrom 1954). The methods used in this study are described by Farris (1959).

Anchovy eggs were taken with a plankton net in the mouth of San Diego Bay on the morning of January 26, 1959. Penicillin (50ppm) and streptomycin (50ppm) were added to the incubation bottles in order to inhibit bacterial growth. Since the blastodisc was well developed (similar to the illustration by Bolin 1936, Fig. 79 stage C), it was assumed that the eggs were spawned the previous night. About two and one-half days after the assumed spawning time, 35 of the 36 eggs had hatched. The temperature had been held constant at 14°C.

The one anchovy egg that failed to hatch, appeared to develop in an otherwise normal manner. The criteria used for normal development were in agreement with the epigenesis as described by Bolin (1936) and homogeneity of embryological events among the 36 specimens examined. At no time prior to the hatching of the other eggs did the egg under discussion appear to differ from the other 35 specimens. Mr. George Mattson of the U.S. Bureau of Commercial Fisheries has observed similar anchovy hatching failures in the laboratory (personal communcation).

After the normal hatching time, the optic vesicles, fins and other body parts of the "imprisoned" anchovy appeared to be normal when compared with the "free" larvae examined at the same time. The pectoral fins and body pigmentation of the imprisoned and free anchovies appeared at the same time. The imprisoned specimen grew in length inside the egg, the body becoming greatly coiled within the egg membrane. The yolk of the imprisoned larva disappeared at the same rate as that of the free larvae. The yolk in all specimens was used up between 5½ and 7½ days after spawning. After the yolk was gone all the larvae died, as was expected, since no attempt was made to feed them.

I suspect that the failure to hatch was the result of the failure of the hatching enzyme. The function and action of this enzyme in salmon is discussed by Hayes (1949, pp. 283–285). According to Hayes, the hatching enzyme, which apparently is activated shortly before hatching, dissolves the egg membrane thereby releasing the larva. The threshing about of the larva within the egg apparently has nothing to do with its actual release from the egg, since the anesthetised larva has been observed to hatch in an otherwise normal manner (Hayes 1949).

Failure to hatch because of the death of the embryo is well known, but death owing to failure to hatch has not been reported for marine fishes so far as I know.

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RAINBOW TROUTS, *SALMO GAIRDNERI*, WITH ANOMALOUS GAUDAL AND PELVIC FINS.

—The object of this note is to describe in *Salmo gairdneri*, an unusual caudal fin in the "steelhead" stage, and three pelvic fins in two wild rainbow trout. Steelhead is the term applied to those of the species which descend to the sea or large lakes and return to streams to spawn.

In April, 1959 while trapping the downstream migration of salmon and steelhead trout in the Yakima River, Washington, the author observed a young steelhead with an unusual caudal fin. The specimen was in its second year of life and following preservation in formalin measured 181 mm. in total length. The normally positioned vertical caudal fin lacked a ventral lobe. In its place was a fin extending from the ventral side of the caudal peduncle on a horizontal plane and joined to the vertical portion of the caudal fin. In appearence the caudal fin was much like an airplane tail with its horizontal stabilizers. Dorsal and side view X-rays illustrate the specimen (Fig. 1).

The unusual occurrence of three pelvic fins in each of two wild rainbow trout was noted among fish taken with rod and reel from the White River, Chelan County, Washington, during July, 1959. While cleaning five trout the author noticed two fish, 7.5 and 8 inches in total length, with the anomaly. In both instances the third fin was located between the normally positioned pelvic fins. Except for being slightly shorter in length the third pelvic fin appeared normal. Maxfield (COPEIA 1959(3):232) observed this same phenomenon on a hatchery-reared rainbow trout.—ROBERT R. FRENCH, *U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Seattle, Washington.*

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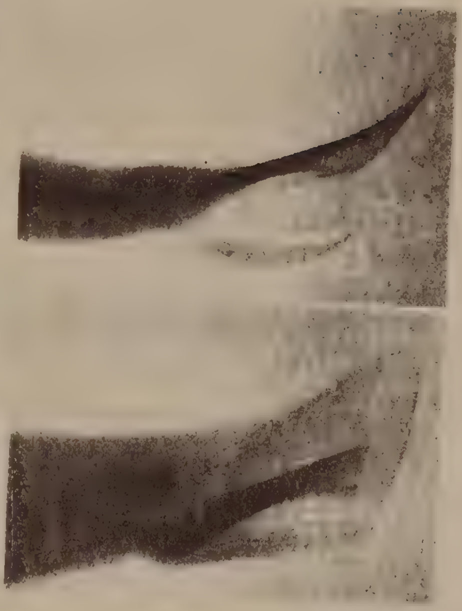

Fig. 1.—Dorsal (top) and side view x-rays of the caudal fin anomaly of a rainbow trout, *Salmo gairdneri*.

Reprinted from the Transactions of the Second Seminar on Biological Problems in Water Pollution, April 20-24, 1959, U. S. Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati 26, Ohio.

ENVIRONMENTAL REQUIREMENTS OF OYSTERS IN RELATION TO POLLUTION

Paul S. Galtsoff, Bureau of Commercial Fisheries, Woods Hole, Massachusetts

ABSTRACT

Oysters tolerate great changes in salinity and temperature. Highly perceptive organs of chemical sense and ability to remain closed for many days are adaptations to the instability of their environment.

The ten major factors of oyster environment may be grouped into two classes of favorable or positive and destructive or negative factors. The positive factors are: character of bottom, temperature, salinity, water movements and food. Only two of these factors, namely, the character of bottom and food, are directly affected by pollution.

Physical characteristics of bottom are changed by the deposition of sludge, by increased sedimentation and by settling of precipitates.

Normal food chain is adversely affected by industrial wastes which destroy many forms utilized as food by adult and larval oysters. Enrichment of water by organic waste, devoid of toxic ingredients, may upset the balance of nutrients and in this way stimulate the growth of useless and harmful forms. Examples of such conditions are found in Great South Bay, Long Island, New York where pollution from duck farms overstimulates the growth of Chlorella-like algae, and in Shelton Bay, Washington, where the red liquor, rich in carbohydrates, induces heavy fouling of Olympia oyster beds by filamentous Melosira.

Temperature, salinity and water movements are affected by pollution only in rare and unusual circumstances.

The five negative factors are: natural sedimentation, changes associated with human activities, competition, predation, and disease. The last three factors are not seriously affected by pollution.

Sedimentation is in general inimical to the life of the oyster. The rate of deposition of suspended matter is increased by pollution because all wastes contain a relatively high percentage of solids, either in solution or in suspension. Toxic materials may be carried by tides and deposited at considerable distances from the place of discharge. Even nontoxic materials, such as sawdust, dumped indiscriminately into coastal waters, may irreparably spoil oyster bottoms and render them uninhabitable by other shellfish.

Artificial changes produced in estuaries by dredging, construction of dams and flood-water barriers, deposition of spoil materials and discharge of various wastes constitute the principal negative factor of oyster invironment. Changes in the configuration of bottom alter the pattern of currents which, in turn, may affect the distribution and setting of larvae. More serious, however, is the discharge of toxic substances. They reduce the rate of feeding and respiration; interfere with the calcium and carbohydrate metabolism; affect the locking mechanism of the adductor muscle; and reduce the reproductive capacity by impeding gonad development, preventing fertilization, or by killing the larvae.

Conditions resulting from the combined action of several factors of natural environment affected by pollution are more serious than the adverse action of a single factor observed in the laboratory.

Under natural conditions, unspoiled by human activities, the organisms of inshore waters live in an equilibrium with their environment. This adjustment is the result of thousands of years of adaptation and natural selection. It can be easily upset by various changes associated with the growth of human population and industrialization of coastal areas. The most pronounced effects are caused by the discharge into water of foreign materials normally not present in it or by the addition of an excess of some of the normal components of sea water. All these changes to a greater or lesser degree alter the normal conditions of the environment and contribute to the pollution of coastal waters.

There is no "good" or "harmless" pollution. All types of pollution are harmful to marine populations, the differences being only in the degree of their effects which may be slight and remain undetected for a long time or may be strong enough to cause almost immediate destruction of certain species. Useful enrichment of sea water by organic matter and nutrient salts can be achieved only by controlled and balanced fertilization. Pollution by domestic sewage and industrial wastes which may contain carbohydrates, phosphates and nitrates fail to produce desirable results because neither the rate of discharge nor the concentrations of nutrients are controlled. The resulting imbalance of nutrients may enhance reproduction of useless and sometime harmful microorganisms which replace the useful forms.

DIRECT AND INDIRECT EFFECTS OF POLLUTION

The changes in the environment often have direct effects on the organisms; they produce mortalities; reduce the rate of survival of larval and juvenile forms; and affect the palatability or usefulness of marine animals for human consumption. The latter instances are of particular importance to shellfish industry, since in polluted waters the bivalve mollusks become contaminated or may lose a considerable portion of the weight of their flesh. Such changes commonly occur among oysters grown in waters affected by domestic and industrial wastes.

Indirect effects of pollution are less apparent but may be equally destructive. The normal ecological environment may be so changed by pollution that some plankton organisms, most useful as food of shellfish, disappear and are replaced by luxurious growth of microorganisms not only useless as food but even harmful to water-filtering mollusks. These changes in the environment frequently remain undetected because of the difficulties involved in observing them and also because of our inadequate knowledge of food requirement of commercial mollusks at different stages of their life cycles. Indirect effects of pollution constitute, however, serious dangers to the survival of shellfish populations and are probably some of the major causes of frequent failures of their reproduction.

INSTABILITY OF OYSTER ENVIRONMENT

Oysters are limited in their distribution to a narrow zone of coastal sea bottom. Inhabiting the estuaries, tidal rivers and bays they exist under rather unstable conditions. The major factors of their environment, such as temperature, salinity and water movements, are subject to daily, seasonal and sometime irregular and sudden changes. In order to survive under such conditions the species must have developed great tolerance and adaptability to these changes. The oyster possesses these qualifications. It tolerates extensive changes in temperature from 0° C. to about 35° C. It can adjust itself to wide fluctuations in the salinities from nearly fresh water to the concentration of salts of more than 3.5 percent. Furthermore, by using the locking mechanism of its adductor muscle the oyster is able to hermetically seal the valves and survive without food or water for about three weeks. Species of shellfish which lack this type of muscular mechanism, for instance the pearl oysters, rapidly succumb to unfavorable conditions in which the edible oysters survive without harm.

TEN MAJOR FACTORS OF THE ENVIRONMENT

The factors of the environment which control the life of oyster populations can be grouped in two large classes: (a) those which are indispensable for the existence and welfare of the population, and (b) those of destructive nature which interfere with growth, reproduction and survival of species. The first group comprises the positive factors of the environment; the second one consists of negative ones. The prosperity of an oyster population is affected by the interaction of all positive and negative factors. The effect of a single factor of the environment can be evaluated by studying the manner in which it controls vital functions of the organism and by determining the optimal conditions under which it operates. For instance, since oysters cease feeding at temperatures about 8° C. and lower, the value of a temperature factor of a given estuary may be expressed as percentage of the number of days the oysters may feed in the locality. Other factors may be evaluated in a similar manner.

Positive factors

The positive factors of the environment are as follows: character of bottom, temperature, salinity, water movements and food. Pollution of water may have direct effects on bottom, salinity of water and food. Temperature and water movements are not affected by pollution except in some unusual and rare circumstances when hot effluents are discharged onto inshore waters or when the rate of discharge is so great that it interferes with the normal pattern of circulation. Such instances may be encountered only in very small bodies of water but even there the adverse effects are rapidly dissipated.

The effect of pollution on physical and chemical characteristics of bottom is fairly common and is frequently well pronounced. Both domestic sewage and industrial waste contain substantial quantities of solids which are rapidly settled in sea water and cover the oyster bottoms. Sediments derived from domestic sewage form sticky, soft sludge of high organic content. Its accumulation on bottom covers and smothers the oysters killing them or rednering them unsuitable for human consumption. If pollution continues unabated for many years the hard or semihard bottom, suitable for cultivation, is converted into soft mud saturated with hydrogen sulfide and entirely unsuitable for the growing of oysters. Highly polluted harbors of the Atlantic Coast may be cited as typical illustrations of these conditions. They are found, for instance, in Jamaica Bay, New York, in Bridgeport harbor and New Haven harbor, Connecticut, in upper parts of Narragansett Bay, in Boston Bay, in Great Bay, New Hampshire and in many other places of our coast. The destruction of formerly productive oyster bottoms by the deposition of sludge or sediments may persist for several decades after the pollution had been stopped. A striking illustration of such a case is found in the formerly productive area in Damariscotta River, Maine, known as Salt Pond and located above the Newcastle-Damariscotta bridge. The bottom of this pond was destroyed by sawdust and trash dumped long ago by the lumber mills. Although the local mills stopped functioning at the turn of the century, the bottom of the bay in 1940 was still covered with a layer of decomposing sawdust 3-4 feet thick. No oysters, of course, could exist in such conditions, but a few live oyster drills were present at the time of my visit.

Changes in the proportions of the chemical constituents of sea water under certain conditions encourage the growth of algae to an extent which interferes with the life of the mollusks. This condition was reported by several investigators who studied the pulp mill pollution in Shelton Bay, Washington. The red liquor, a waste product of sulfite process of pulp making, was discharged at the head of the bay in the vicinity of oyster beds of Olympia oyster, Ostrea lurida. High organic content of the liquor stimulated the growth of the filamentous diatom, Melosira, which covered the entire bed with a thick carpet of algal growth. Soon after the pollution by red liquor had been stopped, the Melsira disappeared in a short time, only to reappear when the discharge of red liquor was resumed.

The organic matter of the domestic sewage encourages the growth of green algae Ulva and Enteromorpha. These species do not interfere with the growth of oysters but their presence serves as an indication of the possible contamination of water.

Pollution has a pronounced effect on the food cycle in sea water. The entire balance of nutrients in sea water may be upset and water becomes overfertilized by nitrogen and phosphorous contained in waste material. This condition was created in Moriches Bay in Long Island, New York, by an unbalanced overfertilization from the drainage of duck farms.

Exceptionally dense blooms of a unicellular alga related to Chlorella appeared in the bay and greatly interfered with the feeding, growth and reproduction of shellfish. These blooms were correlated to the increase in total nitrogen to 90-200 microgram atoms per liter and phosphorous to 20-25 microgram atoms per liter (Redfield 1952). The excess of nitrogen, which constitutes the limiting factor for algal growth, was traced to the discharge of drain waters polluted with duck excreta which contained large quantities of uric acid. This situation was greatly improved by the widening of the channel leading to the ocean and improved circulation in the bay.

Negative Factors

The major negative or destructive factors of oyster environment are sedimentation, changes caused by man's activities, competition, predation and disease. The last three factors, i.e., competition, predation and disease are not seriously affected by pollution.

Sedimentation over the oyster beds is materially increased if the pollutant discharged into inshore waters contains large quantities of solids in suspension. The changes in the physical characteristic of bottom sediments may be so great as to render the grounds unsuitable for oyster population, as has been already mentioned in the discussion of the character of the bottom. In tidal rivers and in the estuaries with strong tidal currents the suspended material may be carried a considerable distance from the place of discharge. In bodies of water of this type the scour areas, where bottom materials are being washed away, alternate with the areas where sediments are deposited. The deleterious action of a pollutant is more pronounced in the latter areas than in the first ones, and consequently the overall effects of pollution may be greater at a certain distance from the place of discharge than in its immediate vicinity. Oyster bottoms of tidal rivers within the areas of industrial developments are particularly vulnerable to such damages.

In many instances careless disposal of vegetable waste by canneries creates unhealthy conditions, which, however, being conspicuous, provoke immediate protests from property owners and are usually rapidly corrected. The principal effect of that type of pollution is the reduction of oxygen content of water and the accumulation of decomposing matter on the bottom.

The discharge of industrial waste containing chemicals which form precipitates in sea water presents a more complex condition. An example of such a case is the disposal of copperas by certain pigment plants. The ferrous sulfate has no commercial value and is discarded as waste after titanium dioxide, a white paint pigment, is extracted from the mineral ilmenite (ferrous titanite, $FeTi0_3$) by sulfuric acid. In some of the plants the rate of disposal of waste byproduct exceeds 150 tons per day. In sea water the dissolved ferrous sulfate is rapidly hydrolyzed lowering the pH and forming basic ferrous salts. The ferrous ion is oxidized to ferric iron, thus reducing the oxygen content of water. The insoluble yellow-brown colloidal precipitate of $Fe(OH)_2$ settles on bottom as a flocculent sediment. Flocculation and settling may take place at considerable distance from the discharge depending on salinity gradients of the place and its hydrography. My experiments show that copperas is not toxic to adult oysters. The precipitate is absorbed by blood cells on the surface of the gills, and iron particles carried out through the mesenchyme are gradually discarded by the epithelium of the mantle.

The flocculent sediment in water affects the plankton. It adheres to the long spines of Chaetoceros and other diatoms and is entangled between the legs of plankton crustacea. In extreme cases the precipitate acts as a coagulant which carries the plankton to the bottom.

The effect of copperas on oyster larvae has not been studied but is probably harmful since the salt contains considerable quantities of copper which is extremely toxic to them.

Precipitation of hydroxides of other heavy metals also occurs when their salts are dumped in sea water. It is known that copper, mercury, lead, and arsenic absorbed by oysters and other bivalves are stored in their tissues and render them unsuitable for human consumption (Hunter and Harrison 1928). It is, of course, a common knowledge that excessive amount of copper is the cause of green discoloration of oysters which renders them unmarketable. These oysters are frequently found in the waters contaminated with industrial wastes of various metal works.

Sedimentation is indirectly involved in oil pollution of waters heavily loaded with silt. Oil is readily adsorbed by clay particles which flocculate and sink to the bottom. In this manner a film of oil disappears from the surface of a polluted area and is deposited on bottom at a distance of several miles from the source of pollution. Strong wave action may release the oil from bottom sediment. The film suddenly reappears on the surface of water and is carried farther by the tide. Such cases of pollution of oyster bottoms have been seen at a distance of several miles from the place of original spillage of oil. Shellfish in contact with minute amounts of oil acquire an unpleasant "oily" flavor and are unmarketable.

Dredging of channels, construction of piers, bridges, draining of marsh areas and similar activities frequently are harmful to oyster grounds. Dredging may adversely affect the oyster bottoms in three different ways: (1) by changing the pattern of circulation, (2) by smothering the grounds with sediments, and (3) by releasing toxic substances entrapped in the deeper layers of mud. Change in the pattern of circulation is often responsible for carrying the oyster larvae away from the places of attachment and the resulting loss of commercial set.

The deposition of sediments stirred up by dredging and coastal construction is usually limited to a zone adjacent to the sites of operations. Dredging may, however, release the toxic substances accumulated for years in the mud of harbors and bays near the industrial cities. This difficulty can be usually foreseen. The release of H_2S by dredging of swamps and estuaries occurs very often but is rarely destructive to oysters, although the escaping gas may spoil the lead paint commonly used on boats and buildings.

Discharge of untreated domestic waste is the principal destructive factor of oyster environment. Its overall effect on sea bottom results in a decrease of the number of species found in a polluted area. This general rule is illustrated by the observations of Reish (1955) on relation of polychaetous annelids to harbor pollution which show the gradual decrease in the number of the species in the polluted waters and their replacement by more tolerant forms. These changes, by themselves, do not affect the populations of oysters. It is of interest to note, however, that a species of Polydora, a mud worm which indirectly affects the oyster, was found by Reish to be predominating in a semihealthy bottom area in Los Angeles and Long Beach.

The major effect of industrial wastes on oysters consists in the reduction of the rate of various physiological functions. The principal function of the oyster is the ventilation of the gills. The current produced by the beating of the ciliated cells of gill epithelium is essential for feeding, respiration, and discharge of excreta. Under normal conditions and at temperatures about 60° to 70° F. the oysters remain open on the average of about 20-22 hours a day. The presence of pollutants reduces the number of hours in proportion to the concentration of toxic substances in the water. If the number of hours closed is plotted against the log of concentration the relationship can be expressed by a straight line as shown in Figure 1. Toxic substances affect the frequency of ciliary beat and interfere with the coordination of the ciliary motion with the result that the pumping capacity of the gills is reduced. The reduction is proportional to the concentration of the physiologically active materials and can be expressed by an exponential curve similar to that shown in Figure 1. This type of relationship was described in studies dealing with the pollution of oyster beds by red and black liquor and by water soluble components of crude oil (Galtsoff 1931; Galtsoff, et al 1947; Chipman and Galtsoff 1949). The results of the latter observations are in agreement with the data reported by other investigators (Seydel 1913 and Veselov 1948) who demonstrated the toxicity of crude oil to fishes.

Slow poisoning of oysters by continuous exposure to low concentrations of toxic material results in poor quality oyster meat and in the loss of their reproductive capacity. The presence of dilute amounts of sulfite (red) liquor in waters of Oakland Bay and adjacent areas of Puget Sound was found to be correlated with the poor quality, lack of reproduction and mortality of Olympia oysters (McKernan, et al 1949). Comparative studies of the glycogen cycles in the two rivers emptying side by side in the Chesapeake Bay showed that oysters in the polluted waters of York River, Virginia, were poorer in glycogen content than the oysters from the adjacent Piankatank River which was not affected by pollution (Galtsoff, et al 1947). Furthermore, the toxic substances in water, as a rule, reduce the length of time the oysters feed, thus diminishing the amount of food they consume.

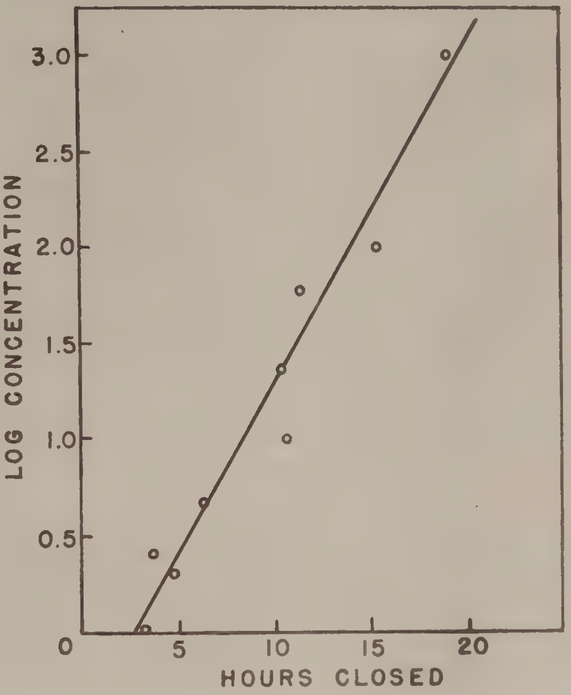

Figure 1. Effect of increased concentrations of an extract of crude oil in sea water on the number of hours the oyster remains closed.

There is evidence accumulated in the laboratories of the Bureau of Commercial Fisheries that oyster larvae are extraordinarily susceptible to minute concentration of copper and DDT. It was reported that a concentration of one part of DDT in forty million used in spray is sufficient to destroy the larvae.

Accumulation of toxic waste in sea water may reach the concentration which is lethal to adult, juvenile and larval oysters. The death of the adult and young oysters usually attracts immediate attention of the oystermen but the destruction of larvae remains unnoticed by laymen. Many instances of the failure of oysters to set can be traced to direct or indirect effects of pollution. This situation exists, for instance, in the polluted area of Fall River, Massachusetts, where the populations of oyster larvae are sometimes destroyed by occasional discharges of toxic wastes from numerous industrial plants situated on the banks of the river.

There is no evidence that competition, predation and diseases are aggravated by pollution. It is reasonable to expect that the resistance of oysters to infection may be weakened by toxic substances in water, but concrete evidence that this is the case is lacking.

COMBINED EFFECTS OF ENVIRONMENTAL FACTORS

So far we have considered the effects of various types of pollution in their relation to a single factor of the environment. This artificial condition, attained only under strictly controlled laboratory experimentation, does not exist in nature. Factors of the environment do not operate singly but always act jointly. One serious weakness of many ecological studies of marine populations is the tendency to correlate the results of biological observations with one or possibly two selected factors of the environment, such as temperature, salinity or hydrographic conditions. In reality, a given factor can exert its effect only in conjunction with other factors. For example, in the studies of the effects of pollution on an oyster population it is impossible to separate the effect of chemical changes of the environment, produced by the pollutant, from the transfer of the pollutant by the movements of water, and from the effects of pollutant on food chain. Likewise, the changes in character of bottom brought about by pollution cannot be segregated from the direct effects of pollutants on the chemistry of the water, oxygen contents, changes in pH, etc. Combined action of several factors may produce greater effect than one caused by a single adverse condition. It has been demonstrated in ecological literature that the results of the joint action of several factors may be different from the effect of the individual factor (Rübel 1935). This general principle is fully applicable to the effects of water pollution on aquatic animals.

Field experiments on mortalities of oysters conducted by Günter (1955) in Texas may serve as an illustration of this principle. He found that the rate of mortality of oysters, not due to predation, at stations where in June-July the salinity of water was high, varying from 35-36 parts per thousand, was about five times greater than the mortality at the other stations located in the areas of lower salinities. Oysters used in Günter's tests were taken from their natural habitat in Texas waters. There was no indication that the specimens which were placed at stations of higher salinity and suffered higher mortality were in any respect different from other oysters kept in water of low salinity. There was no difference between the two groups in the degree of infestation or in the incidence of disease.

Environmental conditions are often responsible for the differences in the mortality of oysters subjected to the same type of pollution. This can be frequently observed among the oysters living in the marginal zones of their habitat, for instance, in the waters of greatly reduced salinities in the upper reaches of tidal rivers, in the upper part of Mobile Bay, Alabama, in Galveston Bay and in Copano Bay, Texas.

It is more difficult to study a joint action of several conditions of the environment than to determine the effect of a single factor. With proper technique and equipment the difficulty can be overcome. Investigations conducted from an ecological point of view should take into consideration the combined action of all positive and negative factors. This approach appears to be more promising in solving the problems of pollution of estuarine waters.

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The three hearts of the oyster. Paul S. Galtsoff.

The open circulatory system of the oysters and other bivalves is characterized by the presence of large sinuses and open lacunae or spaces which receive blood from the arteries. It is obvious that under such a condition effective circulation is impossible. This deficiency is compensated by several mechanisms: the pulsation of the radial vessels of the mantle; the squeezing of blood in the vessels of the gill lamellae by the contraction of gill muscles; the contraction of the wall of the common afferent vein; and by the contractions of the two accessory hearts located on the wall of the cloaca on each side of the adductor muscle. The accessory heart is not a simple tubular structure, as it had been heretofore described; it consists of three large branches, joined at a center in the form of a letter Y. Injection of dyes shows that the accessory hearts are in communication with the anterior pallial arteries, the renal sinus, the efferent veins and the circumpallial artery. It is interesting that the blood from the accessory heart enters this vessel against the ventricular pressure of the principal heart. The contraction wave starts from the center of the accessory heart and goes into two opposite directions. The rate of contraction is independent of the beating of the principal heart and is much slower. The function of the accessory hearts is to oscillate the blood within the pallium.

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A COMPARATIVE STUDY OF UNSTABLE AND STABLE (ARTIFICIAL CHANNEL) SPAWNING STREAMS FOR INCUBATING KING SALMON AT MILL CREEK[1]

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INTRODUCTION

King salmon *(Oncorhynchus tshawytscha)* originating in the Sacramento River are a valuable resource for the sport and commercial fisheries in the State of California. The Sacramento River also contributes to the coastal salmon fisheries of Oregon, Washington, and British Columbia (Fry and Hughes, 1951). A decline in abundance of the resource has caused concern among sportsmen as well as commercial fishermen *(Commercial Fisheries Review*, 1958, Ryan, 1959). Decreases in numbers of salmon returning to the Sacramento River were explained by the California Department of Fish and Game as being caused by pollution, predation, fishing pressure (river catch and expanding ocean troll), loss of spawning area by construction of dams, direct stream damage by various man-created activities, and streamflow and temperature change from water diversion *(Outdoor California,* 1958).

The United States Bureau of Commercial Fisheries, in cooperation with the California Department of Fish and Game, has been investigating the causes of limited production of salmon in the spawning streams of the Sacramento River area. Measurement of spawn losses determined from experimental sampling indicates an average mortality to fry stage of 96 percent from natural causes. It was hypothesized that if man created the unfavorable conditions for salmon production listed above he might also alter conditions in spawning streams to produce larger yields of salmon. The prospect of increasing the numbers of adult salmon by controlling the natural factors that limit production of young salmon made improvement of spawning streams well worth investigating. Studies therefore were undertaken to determine the principal factor limiting natural production, to show how it operates, and to describe means by which production could be improved.

PROCEDURES

Sampling techniques were established to provide measurements of environmental conditions and of salmon egg survival during the incubation period. The progress of survival was followed by planting known quantities of eggs in plastic containers of .07-inch mesh in simulated redds 12 to 14 inches under the streambed (Gangmark and Broad,

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1955). A systematic recording of the environment was made possible by placing two plastic standpipes (Gangmark and Bakkala, 1958) in each artificial redd.

Selection of a site in the natural stream for planting eggs was confined to those areas where natural spawning had occurred, and in addition, involved consideration of two conflicting factors. On one hand we preferred to plant the salmon eggs under swift water where the possibility of siltation and suffocation of the eggs was minimized. On the other hand, the stream velocity at the planting site must be moderate to afford protection against streambed erosion during periods of fast runoff that are normally expected in Mill Creek, a tributary of the Sacramento River. We, therefore, compromised by choosing a site for deposition of test eggs in moderately fast-flowing water but also a site that afforded some protection from high velocities. In previous experiments severe losses of the test eggs were caused by erosion or siltation of the streambed. In addition, the planted eggs became inaccessible for sampling during periods of high water. Consequently, in recent years, these Mill Creek plants have been reduced to 3,000 eggs planted in 30 plastic containers divided equally among three redds. Many times this number are planted in a control-flow stream where access is assured at all times and where equipment is safe from floods.

An unsolved weakness in the method of testing survival of eggs is our inability to observe or record the fate of the eggs that are eroded from the streambed.

Another aspect of the Mill Creek procedures deserving consideration is the influence on survival of artificially fertilizing and planting the test eggs in plastic containers. Reasonable confidence that these procedures do not adversely affect the test eggs is gained from a comparison of survival between naturally spawned and artificially planted eggs from the same environment. Although results of the natural spawning experiments are not included here, production of young salmon has been comparable to, but not as successful as production from the artificially planted eggs. Further confidence in these planting methods is gained from results already obtained which show production of salmon fry in individual containers ranging from 0 to 99 percent. Thus, survival has not been restricted to certain levels by our test procedures and it has been demonstrated that the maximum possible range of survival can be obtained.

CAUSE OF LIMITED NATURAL PRODUCTION

Experiments at Mill Creek Fisheries Station during the last six years, show that mortality of king salmon to fry stage ranges from 85.2 to 100 percent and averages 95.8 percent. It is quite obvious that the incubation stage is the most critical period in the life history of king salmon. From these studies it was determined that unstable streamflow was the principal cause of the losses. This became increasingly apparent after recent floods in California and after the incubation seasons that produced the poor 1956 and 1957 returns (*Commercial Fisheries Review*, 1958). These studies indicated a consistent mortality-freshet relationship over a period of five years.

Effect of Recent Floods in California

In December 1955 and February 1958, floods occurred in most streams of Northern California including Mill Creek. They caused losses of 100 and 98.2 percent respectively of incubating eggs which had been planted in Mill Creek. Personnel of the California Department of Fish and Game, who count adult upstream migrants and sample downstream migrants by trapping at Mill Creek, captured only two and ten downstream migrants during the winters of 1955-56 and 1957-58 respectively (personal communication with R. Hallock, W. Cunningham, J. Riggs, and W. Van Woert). As indicated in Table 1 these counts entailing 2,440 hours of trapping contrast sharply to the count of 1,942 fry intercepted in 1954. Although the Fish and Game Department's installations are some distance upstream from our operations on Mill Creek and the effectiveness of their downstream trap varies somewhat with the volume of flow, the department's counts substantiate data obtained by our sampling methods. The count of adults moving upstream shows that even 1953-54 may not have been a good incubation season, since 1,339 adults were counted at the station in 1957 from 3,743 parent king salmon counted in 1953.

TABLE 1

Survival of King Salmon Spawn in Mill Creek as Determined by Egg-Planting and Migrant Enumerating Methods

		California Fish and Game Counts		
			Downstream migrant sampling	
Incubation season*	Survival of spawn to fry stage (USBCF data)	Total number of upstream adults	Length of sampling period	Number of migrants
	Percent		*Hours*	
1953-54	8.7	3,743	1,992	1,942
1955-56	0.0	1,704	1,274	2
1957-58	1.7	1,339	1,166	10

* No downstream migrant counts available for 1954-55, and 1956-57 incubation seasons.

Reasons for Poor Production in Other Years

Experiments indicate that stream runoff of less than disaster level can create conditions lethal for spawn. The influence of freshets on spawn in five seasons is depicted in Figure 1, which shows that in every instance survival dropped with the appearance of the first freshet of the season. The significant factor in Figure 1 is the strikingly different records noted in 1952-53 and 1956-57 when the first freshets occurred in later stages of development than in the other three seasons shown. In Figure 1 the slope of decline in survival does not necessarily correspond to the intensity of the freshet occurring before the decline. This is explained by the relationship of the time of the freshet to the phase of development of the incubating salmon egg. An extremely "tender" phase extends from the time of fertilization until

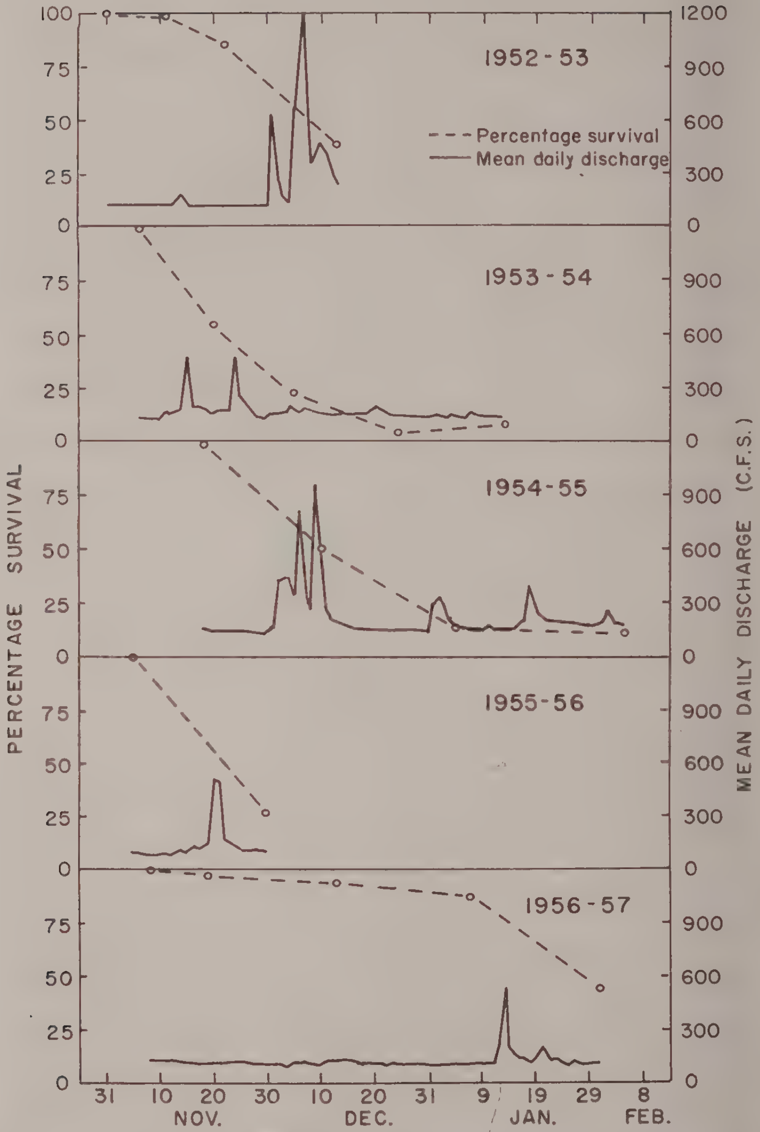


FIGURE 1. Influence of fluctuations in mean daily discharge on king salmon egg survival in Mill Creek, California, 1952-57. Flow records provided by the State of California Division of Water Resources and United States Geological Survey.

the closing of the blastodisk around the yolk. Another period that may be marked by sudden losses occurs when the young salmon emerges from the outer chorion or shell of the egg (Wolf 1957).

During the incubating seasons of 1952-53 and 1953-54 heavy freshets occurred in Mill Creek (Gangmark and Broad, 1955 and 1956). Since king salmon of the Sacramento River area are predominantly four-year-cycle fish, the 1956 and 1957 runs originated from the 1952 and 1953 brood years. As expected, returns were poor in both 1956 and 1957 (*Commercial Fisheries Review*, 1958).

When compared with other tributaries of the upper Sacramento system and with the Sacramento River proper, Mill Creek is not unique in its severe fluctuation in discharge. Table 2 shows the average flow records of some of the important tributaries in this area listed in order of severity of fluctuation. It is noteworthy that this order approximates the order of importance of the streams as salmon producers.

TABLE 2

Flow Rates During the Salmon Spawning and Incubation Season (November 1 to March 31) of the Sacramento River and Some of its Tributaries Located Below Shasta Dam. Flow Rates from U.S. Geological Survey Papers

Stream	Years considered to 1954-55		Flow rate for extreme days during seasons considered			Ratio of maximum to minimum
	From	Total years	Average maximum	Average minimum	Average mean	
			Cubic feet per second			
Battle Creek	1940-41	15	3,603	231	550	16:1
Sacramento River (Near Red Bluff)	1939-40	16	80,350	4,153	14,194	19:1
Mill Creek	1939-40	16	3,392	111	382	31:1
Deer Creek	1939-40	16	4,389	103	465	43:1
Antelope Creek	1940-41	15	2,634	40	215	66:1
Big Chico Creek	1939-40	16	2,824	28	262	101:1
Cottonwood Creek	1940-41	15	12,310	92	1,417	134:1
Cow Creek	1949-50	6	13,043	88	1,205	148:1
Thomes Creek	1939-40	16	4,686	16	444	293:1
Paynes Creek	1949-50	6	1,810	4.4	159	411:1
Elder Creek	1949-50	6	2,314	0	165	----

Based on the relative stability of its flow, the Sacramento River rates higher than most of its tributary streams, for natural reproduction of salmon. In both the 1957 and 1958 incubation seasons, 30 plastic sacks each containing 100 eggs were buried in three experimental redds. Prior to hatching of the fry all of the sacks were eroded away from under 12 to 14 inches of Sacramento River gravel. In the vicinity of the site of planting and downstream from it we found evidence that egg samples may have been plowed out of the Sacramento River gravel by large uprooted trees.

From these data, the role that rapid stream runoff played in limiting natural reproduction of salmon in Mill Creek became evident. Other sources of possible losses at Mill Creek include pollution, high water temperature during spawning, various types of infestation such as saprolegnia, oligochaetes, insect nymphs and larvae, and mechanical damage from trampling by fishermen or cattle. Effects of stream runoff, however, completely overshadowed other causes of egg mortality.

HOW CAUSES OF LIMITED NATURAL PRODUCTION OPERATE

With the knowledge that fast stream runoff was significant in the mortality of spawn, effort was directed toward finding exactly how severe runoff caused these losses. It was determined that mortalities were caused by both direct and indirect factors.

Direct Spawn Losses

Direct losses of spawn were due primarily to erosion of the streambed by high velocities of water. Information as to the fate of spawn washed out is not available, but it is reasonable to assume that once the eggs are washed from the protecting gravel bed out into the stream of violent water flow and shifting gravel, their chance of survival is low. Dead eggs found floating in eddies after periods of fast runoff bear this out.

Indirect Spawn Losses

Indirect losses of spawn occurred from a series of events of diverse and complex nature involving loss of spawning gravel and erosion of soil.

Loss of Spawning Gravel

In streams of the Sacramento River system, loose gravel is constantly washed out and piled high on vast bars where it is no longer available to salmon for spawning purposes. The effect is that adult female salmon must compete for limited spawning areas. This often results in crowding, and causes the later spawners to dislodge the eggs of earlier spawners.

TABLE 3

Mortality Rate of King Salmon Spawn in Relationship to the Dissolved Oxygen in the Gravel Adjacent to Eggs Planted in Mill Creek During the 1956-57 and 1957-58 Incubation Seasons

Dissolved oxygen		Average mortality	
Number of determinations	Amount of oxygen	Number 100-egg tests	Extent of mortality
	P.P.M.		*Percent*
10	< 5	16	37.8
21	5 - < 7	34	13.6
43	7 - < 9	62	12.2
40	9 - < 11	52	9.6
43	11 - < 13	50	10.8
6	> 13	6	3.9

Soil Erosion

Another series of events causing indirect loss of salmon spawn starts with soil erosion and subsequent deposit of silt and sand that clogs the redd. This blockage leads to:

1. Inadequate oxygen: when seepage of water is retarded in the gravel of a stream bed, there generally is a loss of oxygen from the water due to decomposition of humus (Pollard, 1955). Ellis, Westfall, and Ellis (1948) concluded that five p.p.m. (parts per million) is the minimum oxygen concentration for survival of freshwater salmonoids. Table 3 shows the relationship between dissolved oxygen and egg mortalities found during the 1956-57 and 1957-58 tests at Mill Creek. Large mortalities occurred at levels of less than five p.p.m. of oxygen.

TABLE 4

Mortality Rate of King Salmon in Relation to Velocity of Seepage in Gravel Adjacent to Planted Eggs

Seepage velocities		Average mortalities of spawn	
Number of readings	Velocity of seepage water	Number of 100-egg tests	Average mortality
	Feet per hour		*Percent*
21	.5	34	40.0
8	.5 - < 1.0	14	33.1
7	1.0 - < 1.5	14	24.0
3	1.5 - < 2.0	6	10.1
16	2.0 - < 2.5	24	12.9
14	2.5 - < 3.0	20	13.0
25	3.0 - < 3.5	26	10.8
29	3.5 - < 4.0	34	5.3
20	4.0 - < 4.5	20	2.9
4	4.5 - < 5.0	4	3.8
6	> 5.0	6	5.8

2. Poor delivery of oxygen to the eggs (Wickett, 1954) and poor cleansing of metabolic waste products (Wolf, 1957): from the 1956-57 and 1957-58 data taken at Mill Creek, the rate of seepage was related to the survival of eggs. The data are presented in Table 4. It can be seen that the mortality rate of eggs was dependent in large measure upon the rate of seepage of water through the gravel. The data indicate that the optimum velocity is roughly 4.0 to 4.5 feet per hour.

IMPROVEMENT IN NATURAL SPAWNING CONDITIONS

As a result of the studies at Mill Creek, effort has been directed toward reducing or eliminating the principal causes of mortality of salmon spawn by establishing a flow-control area similar to the experimental area at Nile Creek on Vancouver Island (Wickett, 1952).

Experimental Test Area at Mill Creek

The Mill Creek experimental area, previously described by Broad and Gangmark (1956), consisted of a section of an old streambed through which a channel has been bulldozed and from which silt has been flushed to provide an area suitable for tests on incubating salmon

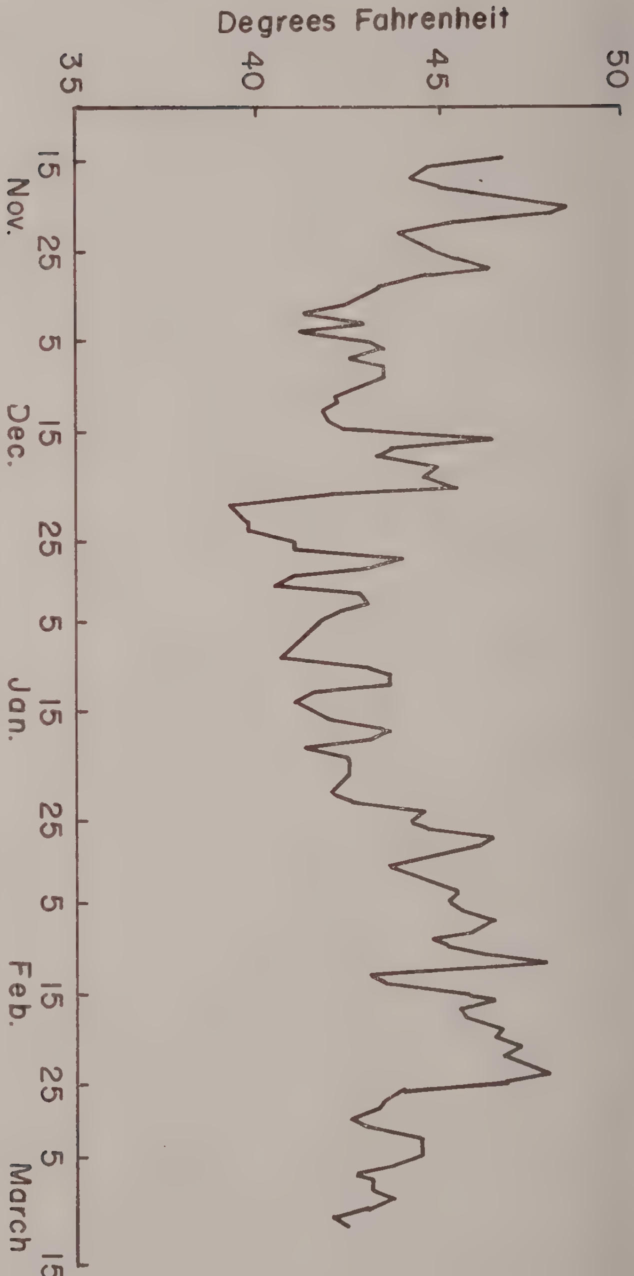


FIGURE 2. Mean daily water temperatures in Mill Creek during the 1957-58 incubation season.

eggs. Two pipes, each 30 inches in diameter and equipped with gate valves, provide for a controlled-flow of water to the area. The amount of silt in the water is reduced before it reaches the test section of the stream by filtering the water through gravel and passing it through a settling basin. A dike protects the area from severe run-off from the main stream of Mill Creek. Adjacent to this controlled-flow area, Mill Creek proper provided an uncontrolled-flow area for comparison.

Comparison of Factors

Testing survival of salmon spawn in the controlled-flow area and in Mill Creek has provided fundamental information on the effect of rapid stream runoff. Stream erosion, temperatures, dissolved oxygen, and seepage rates were compared and measured in these two areas during the 1957-58 incubation season.

Erosion

Rapid runoff eroded out one-half of the planted egg samples in Mill Creek, but no eggs were eroded out in the control area.

Temperature

Temperature was not a factor in differential survival in the 1957-58 tests since the temperature was the same in both areas (Figure 2).

Dissolved Oxygen

In Figure 3 the values obtained during the 1957-58 incubation season reveal a greater concentration of oxygen in the stream gravel in the controlled-flow area than in the open stream. The average level remained above five p.p.m. in both environments. In Mill Creek, however, the concentration of dissolved oxygen at hatching stage, was slightly below the seven p.p.m. considered to be a critical minimum, just prior to hatching, for the chum salmon *Oncorhynchus keta* (Alderdice, Wickett, and Brett, 1958). Nevertheless, in Mill Creek concentrations of

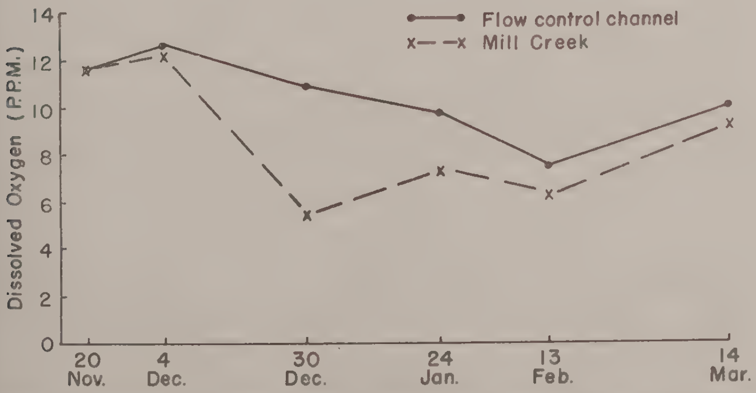


FIGURE 3. Comparison of average dissolved oxygen levels from planted redds in Mill Creek and in the flow-control channel determined at intervals throughout the 1957-58 incubation season. Oxygen samples were obtained in the immediate vicinity of the developing eggs.

oxygen were well above the range of 1.0-1.4 p.p.m. that Alderdice et al. found as the median lethal level (50 percent mortality) for chum salmon spawn just before hatching.

Seepage Rate

Comparing seepage velocities in the gravel in the control area with those in the gravel of the uncontrolled stream provided the most impressive difference between the two areas. The average velocity was 3.5 feet per hour in the controlled area during the 1957-58 season. In contrast, the seepage rate was only 0.3 foot per hour in the uncontrolled stream during a greater part of the season (Figure 4).

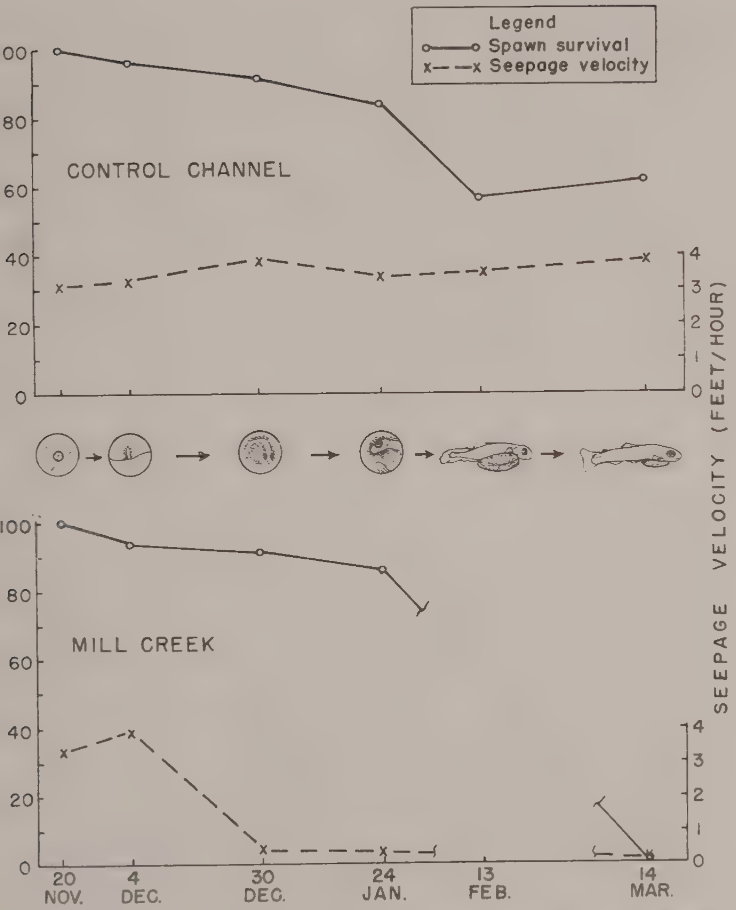
Survival

The superiority of stabilized streamflow to the natural stream conditions in Mill Creek was clearly demonstrated during the 1957-58 incubation season by the production of young salmon in the control-flow area. Based on sampling techniques which indicated a 1.7 percent fry survival of one-half of the originally planted samples, it was calculated that one female produced only 50 surviving young salmon in Mill Creek. The other half of the samples were eroded from under 12 to 14 inches of gravel in the main stream. In sharp contrast, it was calculated that one female produced 3,450 surviving young salmon in the controlled-flow area where conditions of optimum flow and reduced silt prevailed. Survival in the control area was thus 69 times $\left(\frac{3{,}450}{50}\right)$ better than in the uncontrolled stream.

DISCUSSION

Production of salmon in the Sacramento River area is limited by a variety of complex factors affecting the incubation of eggs, principal of which is the silt deposit left by heavy runoff of water that is typical of streams in this area. The means for alleviating damage resulting from heavy stream runoff appears to be control of the natural stream. In the assessment of factors that caused the superior production of salmon in the experimental controlled stream, the most impressive relationship in 1958 was the one associated with seepage rate in the gravel (Figure 4). Wickett (1954) points out that poor seepage may be the cause of failure to deliver an adequate amount of oxygen to the eggs. Wolf (1957) states that inadequate seepage fails to cleanse the eggs of metabolic waste.

Mortality to fry stage was 98.3 percent in the 1957-58 Mill Creek plants. This high mortality was obviously associated with reduced seepage in the gravel, which averaged only 0.3 foot per hour during most of the incubation season. In the controlled-flow area, with seepage rates in the gravel averaging 3.5 feet per hour, survivals were either very good or very poor. Seventy-two percent of the samples averaged 75 percent production of salmon and were associated with good seepages. In the other extreme, 22 percent of the 100-egg samples were all dead—a result of poor seepages that were not always detected by the standpipes.



GURE 4. Relation of average king salmon egg survival to average seepage velocity in anted redds in Mill Creek and in the flow-control channel during the 1957-58 incubation ason. Data for Mill Creek at hatched stage was unobtainable because of high water.

Specific Advantages of Improved Spawning Streams

The experiments at Mill Creek indicate the practicality of increas- g the production of salmon by stabilizing stream-flow. Increased roduction would result from:

(1) Protection to incubating salmon eggs from erosion of the stream-bed by high velocities of flood water.
(2) Conservation of spawning gravel areas, which are critically depleted in the Sacramento River and its tributaries through flood action.
(3) Reduced smothering of eggs by silt.

Other anticipated advantages of flow-control methods include:

(1) Facilitation of predator control (Wickett 1952).
(2) Retention of nutrients (Briggs 1950).
(3) Easier measurement of production for more efficient management of the fishery.

Immediate Plans at Mill Creek

Since production of salmon to the fry stage in this experiment was 69 times greater under stable streamflows than under unstable streamflow in uncontrolled stream areas, the greater part of an old channel of Mill Creek is being rehabilitated for 9,000 feet from where it branches from Mill Creek to where it enters the Sacramento River. The 1958 returning mature king salmon are to be trapped and introduced into this area. Production will be measured by trapping migrants. Of particular interest in this expanded experiment will be the counts of fry after the adults have selected their own spawning site.

Application to Future Management of the Fishery Resource

As a result of the information we have gained at Mill Creek, we are considering the application of flow-control as a management measure for improving production of salmon in California. One suggestion is the establishment of more controlled-flow salmon producing sanctuaries such as the one presently in use at Mill Creek.

Another suggestion is the establishment of new habitats in the Sacramento River tributaries that presently do not qualify as salmon streams. Briefly the ideas under consideration for improving present salmon streams and creating new salmon streams in California embody the following:

(1) That flood waters be impounded in the headwaters of streams by numerous earthfilled or other dams with automatic self-adjusting gates that will permit stabilized flow of water;

(2) That the water-management program be based on the recommendations of all water users and controllers of water. This should assure best use of the water;

(3) That the impoundments be remotely situated so that they will not interfere with the migration of salmonoids; the water be released throughout the year; and the discharge from impoundments be from a stratum of water that provides suitable oxygen and temperature for salmonoids.

SUMMARY AND CONCLUSIONS

1. It has been determined that production of king salmon in the Sacramento River system in California is limited by a series of factors which result from the unstable stream flow found in that area.
2. Direct losses of spawn are caused by erosion of spawn from stream gravel. Fifty percent of planted egg samples observed were washed out and lost in this manner during six years of tests.
3. Indirect losses result from deposit of silt and sand in salmon redds. This deposition reduces seepage rate and leads to poor delivery of oxygen to incubating eggs, low dissolved oxygen levels from humus decomposition, and poor cleansing of metabolic waste products.

4. Indirect losses result from a critical shortage of suitable spawning gravel eroded from the streambed.
5. The effects of flooding were successfully dealt with in a controlled-flow stream at Mill Creek.
6. Settling and filtering methods, made possible by controlled streamflow, reduced siltation in the controlled-flow area.
7. As a result of reduced siltation, seepage velocities averaged 3.5 feet per hour in the controlled-flow area during the 1957-58 incubation season. In comparison, seepage velocities in Mill Creek proper were only 0.3 foot per hour during the greater part of the incubation season.
8. Advantages from controlled-flow resulted in a 69-fold improvement in production of fry.
9. Of the factors that might affect the survival of spawn, erosion and reduced seepage were critical during the incubation season investigated.
10. The demonstration of improved survival by the controlled-flow method has led to expansion of the experimental area. A 9,000-foot section of controlled-flow channel for spawning, where production of young salmon can be measured, is being developed.
11. An extensive and far-reaching consideration for improving existing conditions for production of salmonoids and for creating entire new areas for this purpose is suggested as a result of the work at Mill Creek. This improvement would entail impoundment of flood waters in the headwaters of tributaries and release during dry seasons to stabilize flow.

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Primary Productivity and Limiting Factors in Three Lakes of the Alaska Peninsula

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PRIMARY PRODUCTIVITY AND LIMITING FACTORS IN THREE LAKES OF THE ALASKA PENINSULA

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INTRODUCTION

The lakes draining into Bristol Bay along the base of the Alaska Peninsula are nurseries for juveniles of the red salmon (*Oncorhynchus nerka* [Walbaum]) spawned in the lake tributaries. Other Alaskan Pacific salmons are also taken in the coastal fishery, but the reds (also called sockeyes or bluebacks) contribute most to making the local fishery one of the most valuable in the world. Fluctuations from year to year in the abundance of the red salmon have prompted many investigations, yet various aspects of its ecology remain imperfectly understood.

This investigation was planned to measure and compare the primary productivity of certain red salmon nursery lakes, and determine what factors were limiting. The opportunity to make the study arose through the interest of the United States Fish and Wildlife Service in ecological factors that affect the numbers and condition of young of this important species. Field work was conducted from the Brooks Lake Research Station, established in 1940, which provided living quarters and laboratory facilities. It is supplied primarily by amphibious aircraft. The principal objective of the Station is to determine how physical, chemical, and biological factors affect populations of red salmon in fresh waters.

Considerable evidence suggests that the abundance of this salmon is determined by conditions during its early life in fresh water (Barnaby 1944). Its growth in fresh water, although only a fraction of that achieved in the sea, is of great importance in determining the percentage of a given year class that reaches sexual maturity (Foerster 1954). That food supply is a limiting factor in some drainage systems is suggested by the inverse relationship between the average growth rate of juveniles and their numbers, as found by Foerster (1944). Supporting this viewpoint are the inverse correlations between available zooplankton and size of red salmon populations noted by Ricker (1937). More recently, Nelson (1958), following the growth of red salmon juveniles and smolts in fertilized Bare Lake, found a closer relationship between their growth rate and the gross photosynthetic productivity of that Lake than might have been expected in view of the many environmental factors in addition to food supply.

A logical point to begin the study of food supply in a lake is at the level of the photosynthetic primary producers. These organisms are neither all restricted to photosynthetic production of organic matter, nor do they represent the only primary producers. The photosynthetic carbon fixation by phytoplankton and bacteria has, however, been demonstrated to represent the major part of the organic production in lakes. Chemosynthetic productivity is of secondary importance (Kuznetsov 1956). Changes and differences in this basic productivity within a single lake and between various lakes may be expected to influence, although not always directly, the rate of accumulation of organic matter in successive trophic levels. The natural fertility or lack of fertility and rate of primary production in standing waters are therefore of fundamental importance for understanding and comparing lakes as biological units.

Methods of measuring primary productivity by phytoplankton were developed in the 1920's. According to Steemann Nielsen (1952), the work of Atkins (1922, 1923) was the first attempt at indirect measurement of organic production in the sea. His estimates were based on loss of carbon dioxide and phosphate from the water as it was taken up by phytoplankton. Earlier biologists had relied on direct measure of the standing crop, which, by its static nature, was of limited use in understanding a system constantly undergoing change. A very important step in measuring the rate of photosynthesis was development of the oxygen technique, apparently first used by Pütter (1924) and then by many others, including Gaarder & Gran (1927), Schomer & Juday (1933), Vinberg & Iarovitsina (1939), Riley (1940), Nygaard (1955), and Odum & Odum (1955). Chlorophyll content also has been used to estimate photosynthesis by such workers as Manning & Juday (1941), Riley (1940, 1941), Gardener (1943), Gessner (1949), and Ryther & Yentsch (1957). Daily variations in chlorophyll content are complicating factors in this technique (Yentsch & Ryther 1957). Verduin (1956a) used pH change as still another method of measuring photosynthesis. A major step in increased sensitivity of measuring primary productivity in natural water was achieved with the development of the C^{14} technique by Steemann Nielsen (1951, 1952). The relative merits of the oxygen, CO_2, nutrient uptake, C^{14}, and chlorophyll methods of measuring primary productivity are reviewed by Ryther (1956).

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Paralleling the advance in techniques was growth in appreciation of the complexities of organic transfer through aquatic systems. From the first consideration of the lake as a microcosm (Forbes 1887) through the early diagrammatic representation of food webs (Shelford 1913, Naumann 1925, Perfiliev 1929, MacFadyen 1948) to the trophic dynamic approach of Lindeman (1942) and estimates of "bioactivity" by Ohle (1956), there has been an evolution in understanding the complexity of energy transfer through the ecosystem. The early work of Lindeman provided a very important basis for development of the concept of productivity, although his trophic levels were criticized by Ivlev (1945) as an oversimplification of natural producer-consumer relations.

Confusion has arisen in the use of the words "production" and "productivity," because there has been a tendency to carry along in their meaning the static and deep-rooted concept of biomass. Thienemann (1931), the first to assess the terminology critically, was confused by considerations of energy and matter. Ivlev (1945) thought it inadvisable to use "potential productivity" because it does not reflect the existing state of the body of water in question. This confusion of biomass and energy was generally clarified by MacFadyen (1948) and Dussart (1950). MacFadyen suggested abandoning the term "production" and using "productivity" when speaking of the rate of flow of matter. In the present study, "primary productivity" is used as the net rate of fixation of organic carbon by bacteria and phytoplankton in photosynthesis. During the summer of 1957, I made the first comparative measurements of primary productivity in three red salmon nursery lakes of the Alaska Peninsula with emphasis on physical and chemical factors which were limiting the process.

Drs. K. F. Lagler and G. H. Lauff provided advice and encouragement during this investigation. Drs. D. C. Chandler, L. B. Slobodkin, and J. W. Moffett helped throughout the study and criticized the manuscript. Drs. L. Provasoli and W. Rodhe also provided helpful advice. Dr. W. F. Royce, U. S. Fish and Wildlife Service, established support of field activities under the Bureau of Commercial Fisheries Salmon Survival Investigations in Alaska. Field personnel at Brooks Lake, especially Director T. R. Merrell, R. E. Painter, and W. L. Hartman, helped with the field work. A grant from the Horace H. Rackham School of Graduate Studies provided for the initial Carbon-14 counts. Dr. I. A. Bernstein furnished facilities and technical assistance in gas phase counting. The U. S. Fish and Wildlife Service, Ann Arbor, made the flame spectrophotometer determinations.

GEOGRAPHY

This study area is about 260 air miles southwest of Anchorage, at the base of the Alaska Peninsula, between latitudes 58° and 59° North and longitudes 157° and 154° West (Fig. 1). Except for Lake Becharof, all the work was accomplished within the Katmai National Monument (Fig. 1).

The local aquatic and terrestrial ecology has been profoundly influenced by its geological history. The eastern half of the Katmai Monument is a glaciated region with rugged young mountains and volcanoes of the Aleutian Range. Glaciers are numerous and some of the volcanoes are still active. To the west the land slopes with gentle irregularity beyond the borders of the Monument to Bristol Bay.

On both the eastern and western sides of the peninsula the drainage pattern is dendritic. The proximity of the Aleutian Range to the eastern side gives the streams a steep gradient over their relatively short course to the coast. A few, nearly attaining base level, meander back and forth in the temporary channels on the valley floor before entering the Shelikof Strait. To the west of the divide, although the initial pattern is similar, the streams thread down the longer U-Shaped valleys to lakes or, like King Salmon River, directly into the Bristol Bay. The low land is poorly drained. Small natural ponds and beaver impoundments dot a considerable area of tundra. Mud flats occupy extensive reaches of the immediate coast line.

Although volcanic origins may be considered for lakes in such a region, Atwood (1911), in a survey of the peninsula, suggested that the four large lakes (Kukaklek, Naknek, Becharof, and Ugashik) in the northeastern portion of the peninsula owed their depth and outline, if not their existence, to ice gouging. He further pointed out that except for Ugashik, all were in valley courses leading from the mountains to the shores of Bristol Bay.

The eruption of 1912, originally attributed solely to Mount Katmai, is now believed to have included the eruption of Novarupta. The total upheaval was

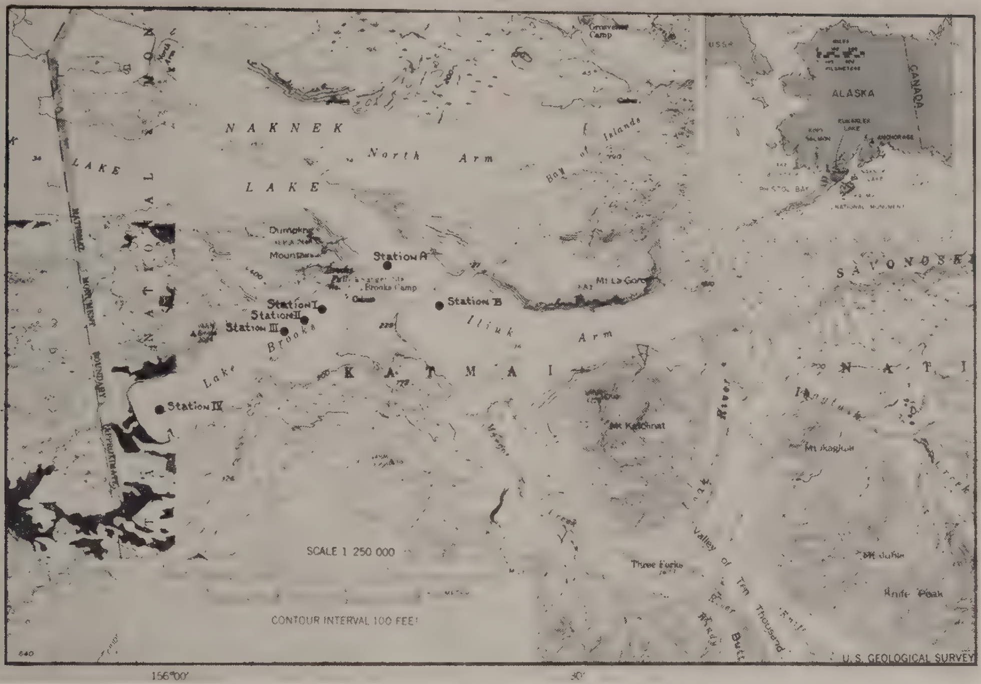

FIG. 1. Geographical location, study area, and sampling stations in the Katmai National Monument.

of great magnitude, flooding what is now called the Valley of Ten Thousand Smokes with more than a cubic mile of tuff (Fenner 1923), as well as depositing a great quantity of siliceous ash over a wide area. The Ukak River and its tributaries have now cut down through a hundred feet of this pumice and ash to form a narrow canyon. Since Robert F. Griggs led the first post-eruption expedition to the area, numerous geologists have visited the area to study the sequence of geologic events that marked the eruption.

Ecologically the area is of considerable interest. The furthest southwestward advance of the white spruce (*Picea glauca*) forests covers a good portion of the monument. This spruce together with cottonwood (*Populus deltoides* Marsh.), balsam (*Populus balsamifera* L.), alder (*Alnus*), and birch (*Betula*) grade gradually into the tall arctic reed grasses (*Calamagrostis sp.*), which in turn yield to the lichens, mosses, and a variety of small flowering plants of the tundra. Short stands of willows (*Salix spp.*) surround the multitude of tundra ponds to the south and west. On the gentler mountain slopes a variety of shrubs and bushes flourish.

The climate is warmer than might be expected at this latitude and is generally maritime in nature. The proximity of the Alaska Current to the east and the Bering Sea to the west have a stabilizing effect on the temperature, although continental air masses cause infrequent extremes. U. S. Weather Bureau climatological data for King Salmon, Alaska, are available since 1928. This is the government weather station nearest to Brooks Lake which maintains complete records. A low of —45°F (—43°C) at Brooks Lake was recorded the winter of 1955-6. The average annual rainfall at King Salmon is 20.39 inches. During the summer of 1957 the 4-month total at Brooks Lake was 17% greater than at King Salmon. A comparison of summer rainfall at Brooks Lake and King Salmon since 1942 gives very similar values. Rainfall at Brooks Lake during June, July, August, and September averaged 1.87, 2.30, 5.31, and 3.64 in., respectively, during 1942-1957, exclusive of 1943, 1945, and 1946. Precipitation during the summer of 1957 was below these averages (United States Department of Commerce Weather Bureau 1957).

THE LAKES

BROOKS

Brooks Lake is 10.7 mi long and varies in width from 2.5 to 4.0 mi. The surface area, exclusive of islands, is approximately 28.2 sq mi (7308.5 hectares). It is 18.9 m above mean sea level, and the long axis lies northeast by southwest. There are three prominent islands in the lake with a total surface area of 66.4 ha. During the 1957 field season the depth of the basin was carefully ascertained with a Raytheon depth recorder. Morphometry was calculated by Olson's (1949) system. Maximum and mean depths were found to be 78 m and 45 m respectively. Shore development was 1.48. The northeast end has a broad, sandy littoral zone extending about a half mile from the shore. The other end of the lake has a similar shelf of about half the width. The northwestern side of the basin drops off more rapidly than the southeastern, reflecting the greater proximity of the mountains to the west.

The general U-shaped basin of Brooks Lake is a smaller and perhaps somewhat deeper model of the other basins of probable glacial origin in the area. An area of over 12 sq mi of the lake has a depth of 61 m or greater, and an area of about 5 sq mi has a depth of 73 m or more. Mountains afford wind protection along the northwest and southwest sides. Both ends are open providing a maximum fetch for winds blowing in the direction of the long axis.

To the northeast, the Brooks River drains the lake into Naknek Lake, 9.2 m below. At the southwest end of Brooks Lake, Headwater Creek, its major tributary, meanders across a broad valley with only a slight gradient near its mouth. A number of small tributaries are found along both sides of the roughly rectangular lake. Those along the southeast side are typically clean, gravel bottomed streams which find their source in the small ponds and low lands at the base of the mountains. Although the five species of Alaskan Pacific salmon utilize these streams, Headwater Creek, and, to a limited extent, the lake shore for spawning, red salmon constitute the important spawning stock. The tributaries to the northwest are smaller and, for the most part, originate near the shore in beaver ponds or narrow gullies. During the 1956 and 1957 seasons, salmon were observed to spawn in only one of these streams.

NAKNEK

Naknek Lake, the largest body of water in the Monument, covers approximately 50,586 hectares at an elevation of 10.36 m. From the main lake, two arms extend to the east. The more northerly arm receives very little of the major drainage. The southerly Iliuk arm receives the outflow of Coville and Grosvenor lakes via the Savonoski River as well as the Ukak River drainage from glaciers and the Valley of Ten Thousand Smokes. Although complete soundings have not been made in the various parts of this lake, extensive areas of water less than 25 m in depth exist just off the mouth of the Brooks River. Contours based on 23 soundings in the southern portion of the lake (exclusive of the Iliuk arm) give an approximate mean depth of 20 m.

Both the Savonoski and the Ukak Rivers contain a great deal of suspended pumice and ash which reduces the transparency of Naknek Lake. The turbidity decreases progressively as one proceeds away from the tributaries toward the Naknek River outflow, but is still quite evident near the mouth of Brooks River where the inflow of clear water is in sharp contrast.

As mentioned previously, these lake basins appear to be the continuation of glacial valleys extending from the mountains to the east towards Bristol Bay. The Naknek Lake basin almost certainly has a deep deposit of pumice and ash from the eruption and from the tributary streams already noted. Rather steep mountains rim the lake. The highest of these is Mount Katolinat, rising abruptly from the south shore of the Iliuk arm to an elevation of about 1402 m.

BECHAROF

Lake Becharof, second largest of Alaska's inland lakes, is approximately 50 mi south of Naknek. Its long axis is about 40 mi in a general east-west direction. The greatest north-south dimension is approximately 15 mi. The large Egegik River drains the lake into Bristol Bay, 35 mi to the west. The outlet, although a rapids strewn with boulders, is navigable to small boats. The lake's shoreline is more regular than that of Naknek Lake and lacks the rim of mountains except near the east end. It is beyond the advance of the white spruce forests and is bordered for the most part by a rocky shore with tundra beyond.

Soundings were taken to a distance of four miles east of the outlet. The bottom was rather flat and sandy in this area with a fairly uniform depth of about 25 m. Greater depths were encountered further east of the outlet. The drainage into the lake is through a number of small to moderate size tributaries.

METHODS USED FOR MEASURING PRIMARY PRODUCTIVITY WITH C^{14}

LAKE STUDIES

The C^{14} technique for measuring primary productivity of phytoplankton populations in natural waters, first presented by Steemann Nielsen (1951), involves the addition of a small amount of radioactive carbon as sodium carbonate to water samples contained in clear glass bottles. Determination of the amount of carbon fixed is based on the assumption that rates of photosynthetic fixation of C^{14} and C^{12} differ only slightly because of the slower uptake of the heavier, radioactive isotope of carbon. This difference of 6%, called isotope effect, is corrected for in the calculations. Because preliminary experiments indicated that non-photosynthetic uptake of C^{14} exceeded the 1% of photosynthetic uptake suggested by Steemann Nielsen (1952), dark bottles were included with each experiment at selected depths at all stations to measure this. For the short incubation periods used it is assumed that dark uptake of C^{14} can be used as an estimate of nonphotosynthetic uptake in the light.

Water samples were collected from selected depths at each station and transferred to 150 ml, clear, glass-stoppered bottles. When all the samples for an experiment were on hand, five microcuries of C^{14} were added to each sample bottle. The sodium carbonate was prepared by Volk Radio Chemical Company, Chicago, in 100 ml serum bottles with an activity of 2.5 microcuries per ml. An automatic hypodermic syringe (Cornwall No. 1251 B D) was adapted to facilitate its rapid injection into the 150 ml, clear, glass-stoppered bottles without danger of contamination (Fig. 2). This procedure allowed a minimal time lapse for C^{14} addition among the bottles at each station and among stations. The time of C^{14} addition was carefully noted so that the isotope would be available to the algae for the same interval in each bottle. Each of these bottles had a metal snap tied to its neck for ease of attachment to hog rings secured at measured intervals to a line which, in turn, was attached to a float at each permanent station.

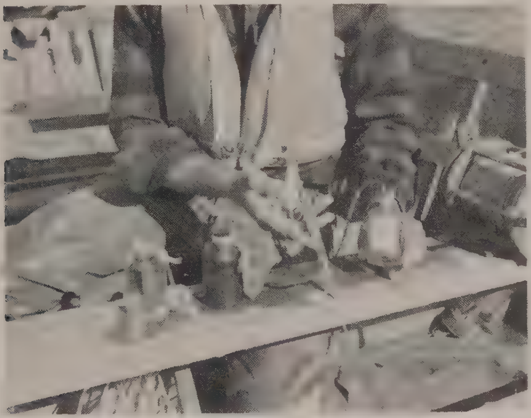

FIG. 2. An automatic hypodermic syringe was adapted to facilitate rapid injection of $Na_2C^{14}O_3$ into sample bottles.

In Brooks Lake the three main study stations were located over depths of 5 m (Station I), 35 m (Station II), and 65 m (Station III), and were as representative as possible of the lake as a whole. The sites were marked by well-anchored buoys. Each float was made from an inflated automobile inner tube securely lashed to a wooden crosspiece. A portable float of the same construction was also utilized as a supplementary station at the south end of Brooks Lake as well as in Naknek Lake and Lake Becharof.

Sample bottles were suspended at one-meter intervals from the surface to 5 m at all stations. At Stations II and III bottles were also placed at 10, 15, 20, 25, and 35 m. In addition, Station III had bottles at 50 and 65 m. After four hours, the bottles in each series were retrieved and placed in a lightproof, insulated wooden box in which they were transported without delay to the laboratory for prompt filtration.

Filtering equipment included a 110-volt centrifugal vacuum pump connected to six vacuum flasks. Each flask had a funnel which was fitted to a coarse porosity, fritted glass disk. Funnel and disk were held securely together by a spring-loaded clamp. A precut, 3.016 cm HA Millipore filter (Millipore Filter Corporation, Watertown, Massachusetts) was sealed between the funnel and the disk by the pressure of the clamp. The 0.45 ± .02 micron HA Millipore filter was selected because of its ability to retain the nannoplankton (Goetz & Tsuneishi 1951; Goldberg *et al.* 1952). Because of activity loss through filters, a porosity of at least 0.45 microns was recommended by Lasker & Holmes (1957).

Light meter readings, Secchi disk depths, and temperatures were recorded at each sampling period. To insure uniform light exposure, the sample bottles were taken one at a time from the lightproof insulated dark box and treated in the following manner. After shaking the sample to resuspend any settled plankton, 100 ml were pipetted into the funnel and filtered at a maximum vacuum of 15-20 in. Hg. Two ml of a pale blue Janus Green B dye solution were added to the sample to show whether or not leakage occurred over the edge of the filter.

After the sample was filtered, 10 ml of .003 N HCl were pipetted onto the filter to remove any residual carbonate adhering to it or to the organisms and to wash any organisms from the surface of the funnel to the filter. Addition of 10 ml of 3% formalin for preservation of the organisms followed. Then the funnel was removed and the wet filter placed in a labeled aluminum sample pan of 3.18 cm diameter. After desiccation, the filter was glued to the pan with a thin film of nitrate dope and stored for subsequent counting.

Because radiation counting equipment was not available at the Brooks Lake Station selected samples were air-mailed to Ann Arbor, Michigan, for counting during the field season. The rest were stored and counted later. The results of the radioactivity determinations on the mailed lots were obtained within two weeks and provided a quality control for the field operations.

To assess total experimental error, duplicate samples were taken at each station once during the period of field operations. Each procedure was duplicated including the collection of two separate water samples at each depth, the preservation of separate plankton samples, etc. A simple wire harness was attached at each level so that the two samples could be suspended at exactly the same depth during the experimental period.

NUTRIENT EXPERIMENTS BY CULTURE

The sensitivity of culture techniques for determining the availability of nutrients for phytoplankton growth has been recognized for many years. Schreiber (1927) working with sea water, Strøm (1933) using Schreiber's approach in fresh water, Chu (1942), Edmondson & Edmondson (1947), Rodhe (1948) Potash (1956), and Provasoli *et al.* (1957), to name a few, have developed and used culture techniques with considerable success.

Phytoplankton population growth has been measured most frequently by direct cell counts (Serfling 1949), although light extinction coefficients (Åberg & Rodhe 1942), chlorophyll (Ryther & Yentsch 1957), volumetric, and gravimetric measurements have also been used. The low plankton concentrations encountered in the natural Alaskan waters used as media rendered all these techniques less applicable than the C^{14} method already discussed (Steemann

Nielsen 1955). Therefore, the main experiments in this study involved a comparison of the rate of carbon assimilation in the different cultures. The measurement of growth was not dependent upon a significant increase in cell numbers during the culture period, but rather upon an increase in the rate of photosynthetic accumulation of organic carbon which may not be immediately manifest in a numerical increase. The extreme sensitivity of this technique for detecting nutrient limiting factors was demonstrated by the author in the laboratory before the field work was undertaken.

During the summer of 1957, 14 culture experiments were conducted. In most of them, lake water with its natural plankton population (chiefly green algae and diatoms) was placed in gallon or half-gallon jars in a floating crib near the lake outlet. Thus, the cultures were at lake surface water temperature and light conditions, and the constant rocking of the crib by current and wave action helped keep the algae in suspension. Cultures were moved daily from place to place within the crib to eliminate any variability due to position. Vitamins B_1 and B_{12}, KH_2PO_4, Na_2CO_3, $MnSO_4$, $MgSO_4$, $Ca(NO_3)_2$, and a variety of oligo-elements (Fe, Cu, Zn, and Co) chelated with EDTA (ethylenediamine tetra-acetic acid), as used by Provasoli & Pintner (1953), were tested separately and in certain combinations to determine which were most limiting. Other culturing was done with Brooks Lake water shipped to the laboratory in gallon polyethylene bottles. In addition to the above mentioned chemicals, $Mg(NO_3)_2$, $NaNO_3$, Na_2SO_4, $CaSO_4$, K_2SO_4, and K_2HPO_4 were used in these cultures.

Bottom sediment extract was also assayed in order to determine its value as a phytoplankton nutrient. This extract was prepared from a sample of the bottom sediment collected at Station II. A volume of 400 ml was thoroughly mixed with an equal amount of lake water and allowed to settle for several hours. The liquid was then decanted and centrifuged twice in a Foerst Constant Speed Centrifuge. As a final treatment to remove microplankton and bacteria, the extract was passed through HA Millipore filters. After analysis for phosphorus, nitrite, alkalinity, hardness, hydrogen-ion concentration, and silica, the filtrate was added to cultures in different percentages by volume. One or more controls were maintained with these as with all culture experiments.

Lake water for the culture media was collected from the surface at Station I. After careful mixing, the total sample was divided into subsamples in 1 gal. or ½-gal. glass jars. Three liters of lake water were used in the former size and 1.0 or 1.5 liters in the latter.

A measure of the rate of production in the cultures was accomplished by further subsampling with the addition of C^{14}. One hundred ml of each culture were pipetted into a 125 ml glass stoppered bottle after first shaking the jar to insure uniformity of plankton distribution. When all these subsamples had been taken, 2.5 microcuries of C^{14} were added to each. The sample bottles were then suspended in the river from a line stretched perpendicular to the direction of river flow in such a manner that the bottles remained just beneath the surface. One or more dark bottles were included as a measure of non-photosynthetic uptake of C^{14}. After a four-hour incubation period, samples were filtered and their radioactivity was measured in the same manner as the lake samples. To be certain that the addition of C^{14} as Na_2CO_3 was not altering the rate of photosynthesis, the oxygen method of measuring photosynthesis was used under controlled conditions. Various concentrations of $Na_2C^{14}O_3$ up to the highest quantity used in lake or culture experiments were tested. Rate of oxygen production was not measurably altered by the addition of sodium carbonate.

In mixed algal populations it is possible that the presence of one species may inhibit the growth of another (Akehurst 1931, Lefevre *et al.* 1949). Pratt (1943), on follow-up work with growth inhibiting substances from *Chlorella vulgaris,* demonstrated the inhibitory effect of this substance on *Chlorella pyrenoidosa* as well as on mixed algal cultures. Rice (1954) and Proctor (1957) showed the existence of similar antimetabolites with a number of different species of algae. In order to learn whether or not such an effect was extant in these experiments, unialgal culture series were conducted to eliminate possible interaction for comparison with cultures utilizing the natural lake plankton populations. A pure culture of the green alga, *Ankistrodesmus falcatus* (Rodhe), was obtained on proteose agar from the Algae Bank of the Indiana University Department of Botany. From this pure lot, the sterile Culture Solution VIII of Rodhe (1948) was inoculated.

The lake water used as a culture medium for the unialgal experiment was prepared by passing 10 liters of surface water from Station I through a Millipore filter, thus removing bacteria, algae, and particulate matter. A liter of the filtrate was then placed in each of nine two-quart culture jars. After filtering the *Ankistrodesmus falcatus* from Rodhe's Solution VIII, the algae were washed with and resuspended in distilled water. Following the addition of six ml (approximately 10^3 cells) to each culture, various nutrients were added. Periodic sampling of these cultures was accomplished in the manner already described, with one exception. Because of the smaller culture volume, only 50 ml subsamples of each were incubated. The C^{14} was correspondingly reduced to 1.25 microcuries. In this experiment, as in the others, duplicate samples of cultures were taken to determine the experimental error of the techniques employed. *Ankistrodesmus falcatus* was again used in subsequent pure culture experiments in the laboratory at Ann Arbor, Michigan.

It has been suggested that results of culture experiments may not be readily applied to the natural environment because restriction of plankton in a container does not duplicate the natural conditions and may favor the development of atypical forms. To offset this, in addition to using the natural lake plankton, every attempt was made to duplicate the natural lake light and temperature conditions in the experimental cultures. However, to strengthen the findings, a test was conducted in the lake itself of nutrients found to be limiting. Since direct application of nutrients to the lake as a whole was not possible and because the C^{14} technique was sufficiently sensitive to rapidly detect changes in the rate of photosynthesis, short term nutrient experiments were conducted at Station I.

SAMPLING SCHEDULE

Radioactive carbon experiments were conducted from the first half of June to September, 1957, with reduced sampling to October. Lake studies were run every five days at the three permanent Brooks Lake stations simultaneously. A diurnal study was also initiated to determine variation in the daily photosynthetic rate. Naknek Lake was sampled every 15 days, and the south end of Brooks Lake at least once a month. Single comparative measurements were made in both Lake Becharof and the Iliuk arm of Naknek Lake. One to three culture experiments were continuously in progress during the summer.

METHODS OF PLANKTON SAMPLING AND WATER CHEMISTRY

During the regularly scheduled C^{14} lake experiments, plankton was sampled by collecting 250 ml of water from the same samples used for the C^{14} uptake measurements, and by taking vertical hauls with a #20 Wisconsin closing net. During the first two sampling periods plankton were collected at each C^{14} sampling depth. After this they were taken on alternate C^{14} sampling dates (*i.e.* every ten days) at the surface and at depths of 5 m at each station, 35 m at Station II, and 35 and 65 m at Station III. On the alternate sampling days, vertical hauls were made with the Wisconsin closing net.

A 10-day schedule at the three permanent Brooks Lake stations was also established for chemical water analysis, Clarke-Bumpus plankton tows, and centrifuge plankton samples. Depths for this schedule were surface and 5 m at Stations I, II, and III, 10 and 25 m at Stations II and III, and 35 and 50 m at Station III.

LABORATORY PREPARATION AND ANALYSIS

From the 250 ml water samples taken for plankton analysis during the lake productivity experiments, 100 ml were preserved by adding formalin to make a 3% solution for inverted microscope analysis and another 100 ml were filtered on a gridded Millipore filter. To achieve a more random distribution of plankton on the filter than could be obtained with the funnels used for C^{14} filtering, 0.875 in. inside diameter cylinders of plexiglass were fitted with flanges so that they could be clamped directly to the fritted disks of the vacuum system. After washing down any organisms adhering to the sides of the cylinders with 3% formalin, the filters were placed on clear, labeled, microscope slides and allowed to dry several hours in a dust free environment. After drying, the filters were cleared with two drops of cedarwood oil and one drop of terpineol. Mounting medium and a number one cover slip were then added. Vertical haul plankton samples were preserved immediately with formalin.

Two liters of water from each sampling depth were centrifuged in a Foerst Constant Speed Centrifuge. The sample was then placed in a calibrated centrifuge tube and hand centrifuged. After a wet volume determination was made, the sample was resuspended by shaking and subsamples were placed in a Sedgwick-Rafter Counting Chamber for identification and enumeration of organisms.

Water analyses included the determination of phosphate, nitrite, silica, turbidity, dissolved oxygen, pH, alkalinity, and total hardness. Photocolorimetric determinations in ppm were made for phosphate, nitrite, and silicon, using standard procedures outlined in the Klett-Summerson photoelectric colorimeter "Industrial Manual."

Turbidity measurements were made with the colorimeter until 24 July when a Hellige turbidimeter became available. The early values were then converted to the Hellige readings. The Hellige turbidimeter, sensitive to turbidity ranges below .80 ppm SiO_2, was more satisfactory than the Klett-Summerson because of the low turbidity encountered in Brooks Lake.

Total hardness determinations were made with a "BKH Water Hardness Outfit." Hydrogen-ion concentration values were obtained with a Hellige pocket comparator, glass disk type, using bromthymol blue-D indicator. Oxygen content was measured by the unmodified Winkler method as nitrogen was below 0.1 ppm (American Public Health Association *et al.* 1955). Water shipped to Ann Arbor in polyethylene containers was analyzed by flame spectrophotometer for magnesium, sodium, potassium, and calcium.

Alkalinity was determined by titration using methyl orange indicator. Available carbon determinations, essential for calculations of photosynthetic rates in C^{14} experiments, were based on total alkalinity, pH, and the dissociation constants of Hutchinson (1957). Actual conversions of pH and alkalinity to available carbon were made from a convenient table by R. W. Bachmann (unpublished).

RADIOACTIVITY DETERMINATIONS

The validity of conclusions based on the measurements of radioactivity depends upon the accuracy of the correction of errors in counting and, since no machine detects all the disintegrations, on the degree of accuracy attained in determining the efficiency of the machine employed. There is a definite probability at any given time of a nucleus disintegrating regardless of the atom's environment. The rate of disintegrations (which register as counts) therefore follows either a normal or a Poisson distribution (Lapp & Andrews 1955). Because the standard deviation closely approximates the square root of the total counts, the desired accuracy can easily be achieved by adjusting the counting time. In this study samples were counted to ± 3% or better.

Natural cosmic and machine radiation must also be corrected for. Since samples from dark bottles were always included in the experiments reported here, these samples not only served to measure counts from non-photosynthetic uptake by chemosynthesis (chemolithotrophy) or absorption, but also served as a basis for subtracting machine and sample background as well. Thus, in one subtraction all background and non-photosynthetic uptake could be eliminated without the necessity of determining these factors individually.

In determining the amount of C^{12} assimilated in photosynthesis it is necessary to know how much C^{14} was available. The $Na_2C^{14}O_3$ used was prepared with an activity of 2.5 microcuries per ml. This absolute activity was based on a National Bureau of Standards calibrated source with an accuracy of ± 10%. The error involved in preparing the $Na_2C^{14}O_3$ in 100 ml serum bottles was only about ± 0.3%.

As noted above, the C^{14} technique necessitates conversion of detected counts to absolute counts. Steemann Nielsen (1952) filtered barium carbonate-C^{14} of known activity onto a collodion filter and plotted a self-absorption correction curve. On the assumption that the geometry of the filtered barium carbonate was identical with the geometry in measuring the activity of filtered plankton, and because the weight of the plankton was always below 0.1 mg per three sq. cm, the activity of plankton could be directly compared with barium carbonate of known activity. Self-absorption in the plankton was therefore disregarded.

Because of the low energy Beta emission of the C^{14} atom (0.155 Mev), I felt that self-absorption should not be ignored nor should a counting efficiency be based on a barium carbonate standard if a better one could be devised. To circumvent these problems, my calibration was based on filtered algae of known activity. To prepare and calibrate this source, duplicate samples of the alga, *Ankistrodesmus falcatus,* and nannoplankton grown in a C^{14} rich medium were killed with formalin, filtered, washed, and resuspended in distilled water.

One set of the duplicate samples was desiccated in flasks, burned to CO_2 (Van Slyke & Folch 1940), and counted in accordance with the gas phase counting method of Bernstein & Ballentine (1950). The high efficiency gas phase counts were then converted to absolute counts with an efficiency value determined by combusting and counting a number of calibrated samples (Series A, June 1949, S. S. No. GS3849, PO No. 155382, National Bureau of Standards).

Quadruplicate samples, taken for the second set, were Millipore filtered, desiccated, and counted with the same equipment used for all the experimental counts. The algae suspension was sufficiently dilute to provide single cell thickness on the filters. The true efficiency of the equipment used in counting an algal source of known activity could thus be obtained by comparison with the gas counts. By removing the C^{14} from the algae and counting it as CO_2, the problems of self-absorption and geometry have been eliminated.

The replicated samples from gas conversion counts and Millipore filter counts allowed a statistical evaluation of the ratio derived (Arkin & Colton 1953). This efficiency was equal to 31.63% with a standard deviation of ± 0.64% (31.63 ± 0.20).

RESULTS

THE PRIMARY PRODUCTIVITY OF BROOKS, NAKNEK, AND BECHAROF LAKES

The need and the desire to classify lakes has long been a motivating force in limnology. In the past a great variety of geographical, physical, chemical, and biological criteria have been employed for this purpose with varying degrees of success. Recently Nygaard (1955) has added productivity to the list. Since productivity must necessarily be a synthesis of the host of variables acting in any lake, it is likely to emerge the most important. Nygaard, who compares his Compound Index with primary productivity measurements, points out the danger of predicting productivity with chemical measurements alone and the improbability of founding the concepts of oligotrophy and eutrophy exclusively on the basis of productivity.

In the study reported here, regular biweekly measurements of photosynthesis with C^{14} were made in Naknek Lake for comparison with the more intensive sampling in Brooks Lake. A single measurement in Lake Becharof was included because of the lake's size, importance, and decidedly different typology. Estimates of productivity on both a unit volume and surface area basis were possible because sufficient measurements were made at each sampling to construct a curve of the variation in photosynthesis with depth. By computing the total area under each curve by planimetry, the total carbon fixation in the euphotic zone was obtained. Mean productivity per unit volume was calculated by dividing this figure by the depth of the euphotic zone, and mean primary productivity per unit of surface area by multiplying the average productivity per m^3 by the depth of the euphotic zone or by the mean depth depending upon which value was lower. This is an important consideration if a meaningful comparison of primary productivity among lakes is to be made on a surface area basis. If the euphotic zone exceeds the mean depth, as was the case in Brooks Lake, the average surface area productivity is limited by the mean depth. In contrast, the estimated mean depth of Naknek Lake is greater than the euphotic zone. An areal estimate of productivity in this lake must therefore be restricted to the depth of the euphotic zone.

A marked diurnal variation in the rate of photosynthesis by plankton populations has been noted by Doty & Oguri (1957) and further investigated by Verduin (1957). A diurnal study was made at Brooks Lake, and the curve (Fig. 3) for the rate of carbon fixation per hour formed the basis for converting the 4-hr measurements to daily net photosynthesis. Solar energy reduced to the photosynthetic range in Langleys per minute (15°C gm-cal/cm^2/min) taken from Brooks Lake pyrheliometer recordings during the diurnal study is also given.

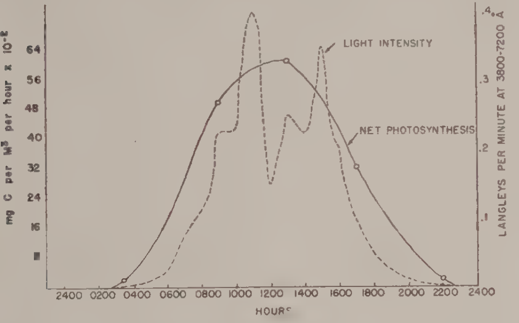

Fig. 3. Diurnal curves for the net rate of photosynthesis and pyrheliometer values for variation in light intensity at Brooks Lake on 1 September 1957.

All measurements were corrected for seasonal variation in the visible portion of the spectrum (4000 Å to 7000 Å) penetrating a smooth water surface at sea level. The solar radiation values used were monthly averages of the U. S. Weather Bureau as compiled by H. B. Gotaas and W. J. Ozwald (unpublished), interpolated to 58° 30′ North latitude, and corrected for average monthly sunrise to sunset cloud cover during 1957 (Fig. 4). Average monthly cloud cover data were obtained for the King Salmon Weather Station (58° 41′ North, 156° 39′ West) from the Weather Bureau, U. S. Department of Commerce.

The most striking feature of a comparison between the productivity of these lakes is the much higher rate per unit volume in Naknek Lake as compared with either Brooks or Becharof Lakes (Table 1). Because of the limited euphotic zone in the shallow south arm of Naknek Lake, and despite a rate of carbon fixation per unit volume over three times that of Brooks Lake and 17 times that of Lake Becharof, the difference in productivity per m^2 of surface area between Brooks and Naknek Lakes is not great. This has been generally recognized in other lakes (Ruttner 1952, Ohle 1956). No estimate for Lake Becharof is included because the mean depth is not known. On the basis of transparency, however, the euphotic zone probably exceeds 70 m at mid-day. The accuracy in estimation of the euphotic zone is dependent upon the degree of precision in determining the average "compensation point" (the place at which photosynthesis balances respiration; Jenkin 1937). This depth necessarily moves upward with decreases in light penetration and downward with increases. Estimates for compensation depth vary from 7 m at Woods Hole harbor to 100 m in the Sargasso Sea (Clarke 1954). Talling (1957) reviews the subject briefly in a formulation for "Respiration losses and the 'compensation point.' "

In Brooks Lake the vertical euphotic zone varied in depth from about 25 to over 50 m, with an average of 46 m for the seasonal sampling periods. This is fortuitously close to the mean depth of 45 m which is used in this study for the areal estimate of productivity in the lake. The considerable difference in the rate of carbon fixation on a clear day as opposed to a rainy day is illustrated by Fig. 5. On these two days the mgC/m^3/day is within about 10% of being proportional to the available light energy, as measured by pyrheliometer. The production on the extremely cloudy day (17 August) corresponds to Nygaard's (1955) figure for reduction of light intensity to abou 10% of that encountered on a bright day. In contra to the deeper stations, Station I exhibited light inhibition (Edmondson 1956) on the bright day as evidenced by higher productivity on the dark day.

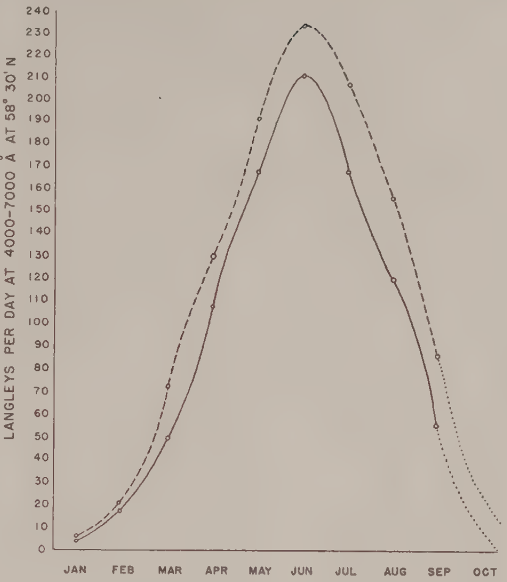

Fig. 4. Seasonal variation at 58°30′ North in the visible portion of the spectrum (4000 Å to 7000 Å) penetrating a smooth water surface at sea level. Solid line corrected for cloud cover; broken line not corrected for cloud cover.

In Naknek Lake the minimum compensation dept was found to be about 14 m. Extreme fluctuations in transparency coupled with those of light intensity would extend this zone considerably on bright days if lake depth allowed. Strickland (1958) has noted that the steady compensation depth at noon will be only 4-5 m below the 24-hr mean compensation depth. Although the mean depth of Naknek Lake is not known, an estimate of 20 m was made from 23 soundings in approximately 60 sq mi of lake west of the Iliuk arm. All measurements of photosynthesis in Naknek Lake extended to 13 m and some to 17, and the depth of the euphotic zone averaged about 16 m; this depth was used for an approximation of carbon fixation per m^2 of surface area. Because sampling dates in Brooks Lake bracketted those in Naknek

TABLE 1. Rates of photosynthetic carbon fixation in three lakes of the Alaskan Peninsula in 1957.

NAKNEK[1]			BROOKS[2]			BECHAROF	
Date	mg C/m³/Day	mg C/m²/Day	Date	mg C/m³/Day	mg C/m²/Day	Date	mg C/m³/Day
20 June (10)[3]	10.23	163.66	18 June (10)	3.80	170.90		
6 July (9)	14.05	224.80	3 July (8)	4.87	219.14		
20 July (5)	10.79	172.61	23 July (8)	4.19	188.73		
4 August (9)	8.71	139.43	2 August (2)	3.10	139.45		
19 August (4)	10.42	166.64	22 August (2)	1.96	88.07	23 August (2)	0.63
5 September (9)	10.69	171.12	2 September (8)	3.19	143.64		
Mean	10.81	173.04		3.52	158.32		0.63
Experimental Error	±.09			±.16			

[1] Estimate of mean depth 20 m based on 23 soundings. Euphotic zone 16 m.
[2] Mean of Stations II and III. Mean depth of Brooks Lake 45 m.
[3] Estimated cloud cover (10.0 equals complete cloud cover).

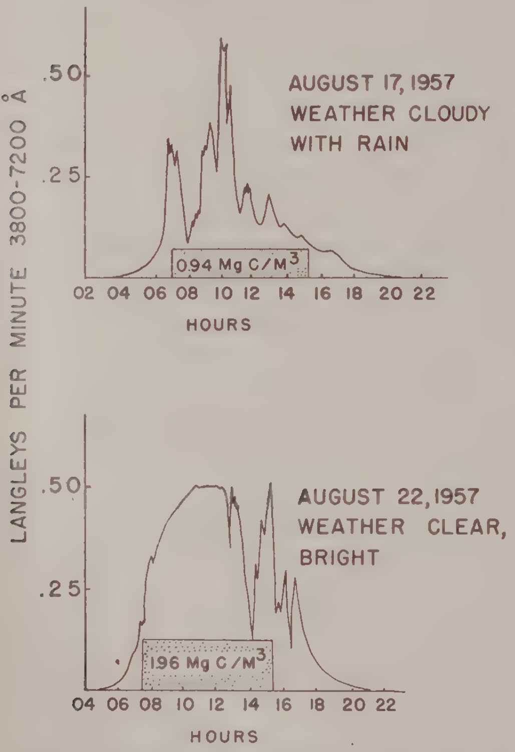

FIG. 5. Average net photosynthesis with variation in solar radiation at Brooks Lake Stations I and II.

Lake, the dates showing the greatest similarity in weather conditions were used for comparison in Table 1.

The relationship of Secchi depth to the compensation point has received attention in the literature since Poole & Atkins (1929) calculated an approximate ratio of 1.7/Secchi depth in meters for the extinction coefficient of visible rays. Verduin (1956b), in reviewing some of the literature on the subject, gives values of 2.5 to 5.0 times the Secchi depth for estimations of the compensation point. The ratio of the mean depth of the euphotic zone and the mean Secchi depth in Brooks Lake gives a factor of 3.6 with variation at least as great as those noted above. Naknek Lake, with an average Secchi depth of only 3.9 m, had a ratio of 4.5. This difference probably resulted from the human eye's being more sensitive to the longer wave lengths of a given light energy favored by turbid water (Sverdrup *et al.* 1942). The approximate nature of Secchi disk conversion factors may result in errors of 25% or more from variation in back-scattering of light encountered in natural waters (Strickland 1958).

VARIATION IN PRIMARY PRODUCTIVITY WITHIN BROOKS AND NAKNEK LAKES

The sites of Stations I, II, III, and IV (Fig. 1) were selected not only to provide a good average estimate of the primary productivity of Brooks Lake, but also to serve as an accurate comparison between different areas in the lake. The first three Brooks stations, each sampled 16 times during the summer, formed a matrix of 96 measurements for a comparison of carbon fixation in the first 5 m of Stations I, II, and III, 144 for the first 20 m of Stations II and III, and 176 measurements for the first 35 m of these last two stations.

For easier comparison with the four sampling dates at Station IV, these data have been arbitrarily grouped in Tables 2, 3, and 4 as the means of four consecutive dates covering each of four 15-day periods. This grouping of Stations I, and II, and III has the further advantage of combining a variety of light conditions since each group includes at least one bright day and never more than two.

TABLE 2. Rates of primary productivity in mgC/m³/-day for the first 5 m of four Brooks Lake Stations. Measurements were made at Station IV on 26 June, 22 July, 15 August, and 6 September respectively.

Dates	Station I (5 meters)	Station II (35 meters)	Station III (65 meters)	Station IV (35 meters)
18 June to 3 July......	4.59	4.85	5.55	3.89
8 July to 23 July......	2.91	2.59	3.98	3.40
28 July to 12 August...	2.82	3.68	3.59	4.82
17 August to 2 September.......	2.52	2.70	3.31	5.55
Mean................	3.21	3.45	4.11	4.42
Standard Error........	.05	.05	.12	.19
No. of Measurements...	96	96	96	24

TABLE 3. Rates of primary productivity in mgC/m³/-day in the first 20 m of three Brooks Lake Stations. Measurements were made at Station IV on 26 June, 22 July, 15 August, and 6 September respectively.

Dates	Station II (35 meters)	Station III (65 meters)	Station IV (35 meters)
18 June to 3 July.	6.01	6.08	5.92
8 July to 23 July..	2.45	4.80	4.40
28 July to 12 August.....	3.24	3.82	9.86
17 August to 2 September...	2.42	2.80	4.19
Mean............	3.53	4.38	6.09
Standard Error...	.07	.12	.14
No. of Measurements........	144	144	39

Even preliminary comparison of sample radioactivity counts by variance analysis indicated a very significant statistical difference between stations. Although the average starting time differential between Stations I and III was only 20 minutes, this difference, because of peak photosynthesis about noon, was found to favor the earlier starting time. In the three comparative tables (2, 3, and 4), the values for Stations I, II, and III were corrected on the basis of the diurnal curve to the same starting time on each data before statistical comparison of the rates of productivity. This correction, although slightly reducing the differences between the three permanent stations, did not alter the trend or the significance of these differences.

The primary productivity at Station IV is only an approximate comparison because productivity measurements could not be taken there and at the three permanent stations on the same day. Meteorological conditions could therefore bias the results of sampling carried out on four dates. In this respect, it is of interest that two of the measurements were made on cloudy days and two on clear days.

In comparing the first five m of Stations I, II, and III, it is evident that a direct relationship exists between the average rate of primary productivity in the first five meters and the depth of the stations (Table 2). In addition and perhaps more important is the trend for higher production per unit volume as one proceeds away from the outlet in the direction of the major tributaries.

TABLE 4. Rates of primary productivity in mgC/m³/-day in the first 35 m of three Brooks Lake Stations. Measurement made at Station IV on 15 August.

Dates	Station II (35 meters)	Station III (65 meters)	Station IV (35 meters)
18 June to 3 July..	4.45	4.85	
8 July to 23 July..	2.19	4.05	
28 July to 12 August.....	2.84	4.22	8.18
17 August to 2 September...	1.79	2.24	
Mean............	2.82	3.84	8.18
Standard Error...	.05	.07	.21
No. of Measurements........	176	176	12

When all 16 dates are compared, Station II is just significantly higher in production at the 0.05 level by Wilcoxon sum than Station I. Predominant WSW winds during July caused a concentration of plankton in the vicinity of Station I. If the four measurements in July are excluded the difference is significant at the 0.01 level.

When Station II is compared with Station III the degree of significance by the same test increases to the 0.025 level. The greatest difference (significant at the 0.01 level) is obviously between Stations I and III. This trend in higher production rates is retained by Station IV.

A comparison of the first 20 m of the three stations yields very similar results to a comparison of the first 5 m (Table 3). Station IV again retains the trend, even if the unusually high productivity of 8 August were excluded from the average. The difference in productivity per unit volume between the first 5 m and the first 20 m of Stations II and III is not significant.

A decrease in average productivity per m³ is evident when an additional 15 m of depth is included in the comparison (Table 4). Station III is consistently more productive in the first 35 m than Station II, at a significance level of 0.005. The only date when measurements extended to a depth of 35 m at Station IV was 15 August. This was a bright day and the warmest of the summer, with a record high of 83°F recorded at the Brooks Lake weather station. The clear conditions that prevailed and the high phytoplankton population doubtless provided a higher than average production there, but even at half the rate the trend of higher productivity toward the tributary end of the lake is maintained.

On 4 August parallel primary productivity measurements were made in the Iliuk arm (Station B) and the regular station (Station A) on Naknek Lake 3 mi to the west of Station B (Fig. 1). These measurements were to compare the primary productivity of the water at Station A with water nearer the mouths of the Savonoski and Ukak Rivers. Because of the contribution of ash, pumice, and glacial outwash from these two streams, the Secchi depth at Station B was only 2.5 m as compared with 6.5 at the regular station. Although temperature recording equipment was inadequate for precision, thermometer values from the water samples at each depth above 10 m show an average increase of 1.8°F from Station B to Station A. Below 10 m the temperatures of the two stations were identical.

The rate of carbon fixation at different depths at Stations A and B in the two water columns is illustrated in Fig. 6. Although light inhibition at the surface was more the rule than the exception in Naknek Lake as well as in Brooks Lake, the measurements of 4 August were made under cloudy conditions. This is the probable explanation for the high photosynthetic rate at the surface, as there was not a significant difference in the plankton between the surface and one meter. The variability in productivity with depth reflects the heterogeneous distribution of phytoplankton which was evident from centrifuge and inverted microscope analyses of plankton in both Brooks and Naknek Lakes. The mean productivity for 13 m at Station A was 8.71 mgC/m^3/day as compared to 6.10 mgC/m^{33}/day at Station B. Station A is more productive than Station B at all depths, except between 4.0 and 6.5 m. The lower productivity of the water column at Station B is probably not the result of lower temperature, since Station B is cooler between 4.0 and 6.5 m than Station A and still has higher production between these depths. Lower temperatures tend, also, to reduce respiration more than they reduce the rate of photosynthesis (Spoehr 1926).

The rapid decline in photosynthesis below 7 m at Station B suggests that light limitations imposed by the higher turbidity are responsible.

A comparison of all routine water analyses during the summer shows little detectable difference among the stations (Table 5). Analyses for phosphorus and nitrogen were near their limits of detectability with values below 0.0008 ppm registering as 0. When all depths are included at Stations I and III, there is a trend towards higher phosphorus content as one proceeds from Station I to III. If, however, only the first 5 m are included in the comparison, the trend is reversed. Nitrite nitrogen is appreciably higher at Station IV than it is at the other Brooks stations. Silicon increases towards Station IV regardless of whether only the first 5 m or the entire water columns are considered.

A comparison of Naknek Stations A and B similarly show only small differences in the amounts of the elements measured. Station B, nearer the main tributaries gave slightly higher average silicon, phosphorous, and total hardness values with nitrogen and alkalinity slightly lower than at Station A. Phosphorous and nitrogen values are probably at or close to their extreme range of reliability. In respect to the amount of silicon, which is very likely the most reliable of the photocolorimetric determinations reported here, it is of interest that the 13 m value (11.6 ppm) at Station A is the same as the mean value of the surface and 13 m at Station B. The surface value at A is lower (10.2 ppm). This difference might result from silica removal by diatoms in the surface layers, but more probably, since temperatures were the same below 10 m at the two stations, from the presence of the denser water mass from Station B close to the bottom at Station A.

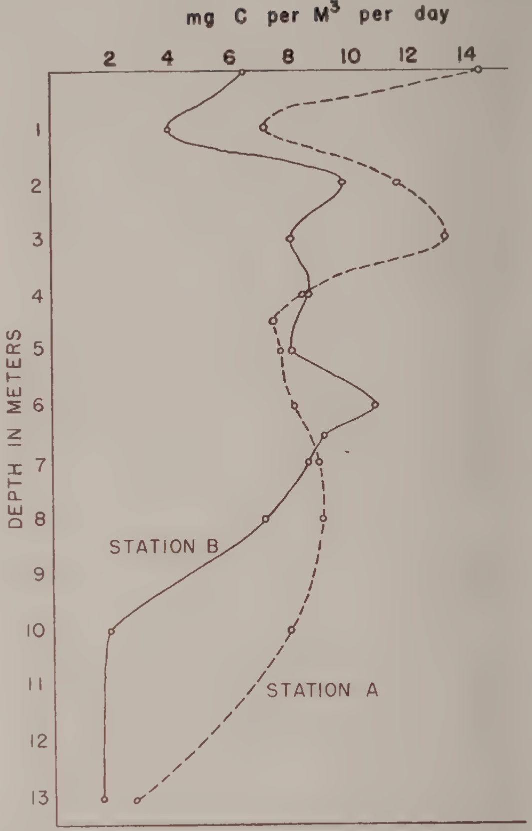

FIG. 6. Changes in photosynthetic rate with depth at Naknek Lake Stations B (solid line) and A (broken line), 4 August 1957.

TABLE 5. Water quality in three Alaskan Lakes, 1957. Values in ppm.

Lakes	BROOKS[1]				NAKNEK[2]		BECHAROF[3]
Stations	I	II	III	IV	A	B	
Phosphorus	.0065	.0070	.0073	.....	.0087	.0095	.0083
Nitrite	.0015	.0012	.0019	.0038	.0083	.0050	.0030
Silicon	10.45	10.58	10.77	11.95	10.90	11.60	1.04
Total Hardness or ppm $CaCO_3$	36.13	35.17	35.48	.....	69.50	71.0	24.90
Bound CO_2 as ppm $CaCO_3$	31.79	31.48	32.00	31.54	35.30	35.10	18.00

[1] Stations I, II, III, and IV, all comparative values July 4 to September 3, 1957.
[2] 4 August 1957 Mean of 0 and 13 m.
[3] 23 Ausust 1957 Mean of 0, 15, and 35 m.

The variation in productivity in Brooks and Naknek lakes from June to October is illustrated by the curves in Fig. 7. Both of these show very irregular seasonal decline in primary productivity from a high in June. If it were not for the comparison of Stations I and II, a histogram would be a better representation of these data (Rodhe *et al.* 1956). Diminishing light as the season progresses is generally recognized as a dominant factor at higher latitudes (Livingstone *et al.* 1958). Nutrient deficiencies may also contribute to a seasonal decline.

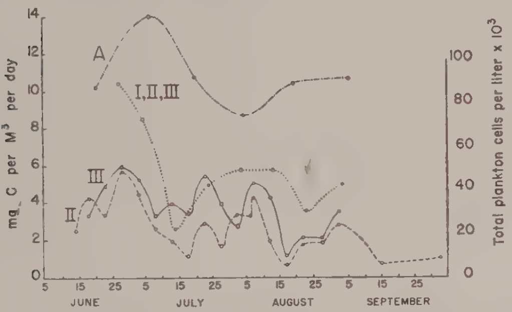

FIG. 7. Seasonal variation in photosynthesis at Brooks Lake Stations II (– – –) and III (——); and at Naknek Station A (– · – · –). Also total phytoplankton at Brooks Stations I, II, and III (· · · · ·).

Thermal stratification, although weak in comparison to more southerly latitudes, was evident by late June and remained until early September when there was evidence of mixing to 35 m. Temperatures in Naknek Lake were about two degrees warmer than in Brooks Lake during the summer, although daily variations were large in the shallower waters of both.

The seasonal change in the total phytoplankton of Brooks Lake (derived from the means of Stations I, II and III) is in rather good agreement with productivity measurements and lends support for a usable relationship between standing crop and rate of production estimates for major changes in productivity during a season (Fig. 7). Verduin (1956a) presents a formula for such estimates from standing crop measurements. Unfortunately, if nutrient or other factors are limiting, a crop built up before this deficiency may be producing very little additional organic matter at the time the estimate is made. In this situation standing crop measurements would give very unreliable values for the rate of production.

As might be expected at this northern latitude the dominating Phylum (Division) was the Chrysophyta. Its important genera were *Melosira, Stephanodiscus, Fragilaria, Asterionella, Tabellaria, Synedra,* and *Navicula.* The diatom population followed and was primarily responsible for the trimodal curve shown in Fig. 7. Next in abundance of both species and numbers were the Chlorophyta. The green algae were abundant in the samples taken in late June, and declined gradually throughout the rest of the summer except for a short lived increase at Stations III and IV in early August. *Phacotus, Pediastrum, Ankistrodesmus,* and *Dictyosphaerium* were the most abundant genera. Of the Cyanophyta, Microcystis and Lyngbya were the only representatives evident throughout the summer. They formed a significant portion of the phytoplankton in the second half of August.

The total zooplankton population in Brooks Lake (measured at Stations I, II, and III) declined steadily throughout the season. The copepods were more abundant in the lake than cladocerans.

EXPERIMENTS ON NUTRIENT FACTORS LIMITING PRODUCTIVITY

The mere presence of chemical substances in the environment, although recognized as a valuable guide for pure culture studies (Provasoli & Pintner 1953), does not necessarily prove their biological availability (Potash 1956). Nevertheless because of the complexity of growth factors in natural waters (Hutchinson 1944), bioassay may be expected to reflect limiting factors better than chemical analysis of the environment.

As described under "Methods," culture series were run to identify the role of various nutrient factors in phytoplankton production in Brooks Lake during the summer portion of the red salmon growing season with three experiments in Naknek Lake and Lake Becharof for comparison. By starting Brooks Lake cultures at regular intervals, it was possible, further, to detect progressive seasonal changes in these limiting factors.

Although cultures were maintained for a sufficient time to allow significant population increases, the effect of specific nutrients on rate of carbon fixation was detectable (with C^{14} as a tracer) within a few minutes or hours after their addition to the media.

To demonstrate the efficiency of the method before field work was undertaken, a nitrogen deficient culture of *Scenedesmus quadricauda* Turp. was divided into two equal volumes. Five ppm of nitrogen was added as $Ca(NO_3)_2$ to one; the other was maintained as a control. Equal amounts of C^{14} were added to both. These were then subsampled four times during the 30-minute period immediately following the addition of $Ca(NO_3)_2$ and C^{14}. Fig. 8 illustrates the high sensitivity of this technique for measuring the increase in rate of photosynthesis initiated by the addition of $Ca(NO_3)_2$ to the nitrate deficient culture. Steemann Nielsen & Al Kholy (1956) have demonstrated that the C^{14} technique is applicable under conditions of phosphorus and nitrogen deficiency, although the discrepancy between the C^{14} and O_2 determination of photosynthesis is reduced by nitrogen and phosphorus addition (Ketchum *et al.* 1958). This is an important consideration since some of the measurements in the Alaskan lakes studied as well as in cultures were made under suboptimal concentrations of these two elements.

The first Brooks Lake culture experiment was started on 23 June and was maintained until 8 July. Of the variety of nutrients added, $MgSO_4$ was most

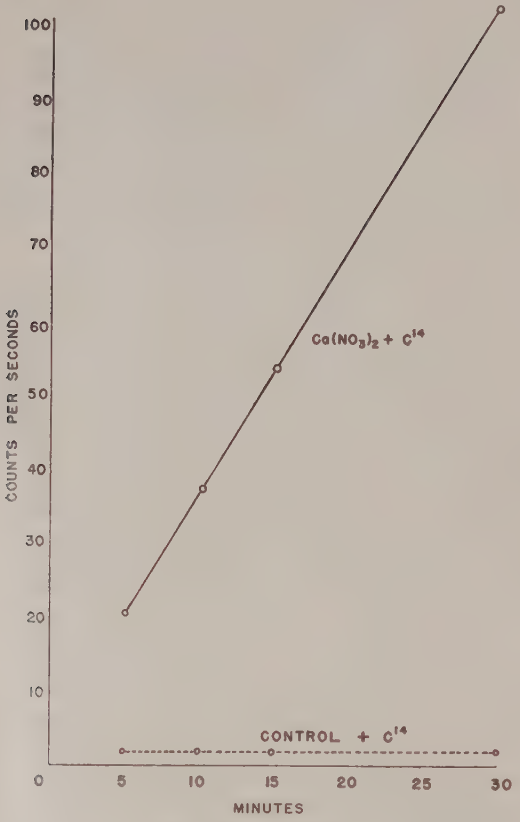

FIG. 8. C^{14} uptake with the addition of $Ca(NO_3)_2$ to a nitrogen deficient culture of *Scenedesmus quadricauda* Turp.

conspicuous as a stimulant to photosynthesis (Fig. 9). Although evident throughout the summer, the increase in the rate of carbon fixation stimulated by the addition of 9 ppm $MgSO_4$ was most pronounced in June. This corresponded to a high population of green algae (especially *Pediastrum* and *Ankistrodesmus*) and diatoms. That $MgSO_4$ was still in short supply in early July is indicated by a significantly higher production value in the culture of that month to which it had been added (Fig. 10). Similarly, the pure culture experiment started on the last day of July showed an appreciable gain upon the addition of this nutrient (Fig. 11).

In testing various concentrations of $MgSO_4$ with natural plankton populations, the quantity used initially, amounting to 9.0 ppm (1.82 ppm of Mg and 7.18 ppm of SO_4), was found to be about optimum. This concentration is within the range used by Rodhe (1948) to obtain optimum growth with *Ankistrodesmus falcatus* and is close to the quantity used by Potash (1956) in pond water with the green alga, *Kirchneriella subsolitaria* G. S. West, as an indicator organism.

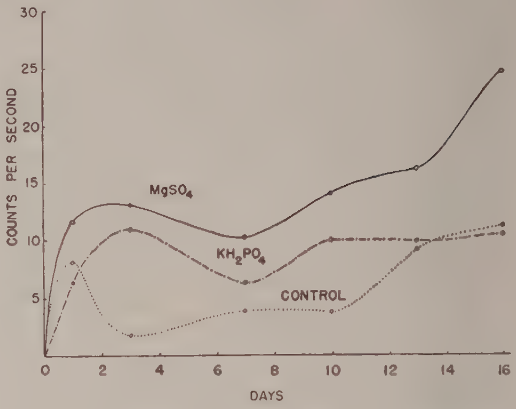

FIG. 9. Relative photosynthesis in phytoplankton cultures of Brooks Lake water to which $MgSO_4$ or KH_2PO_4 were added on 23 June 1957.

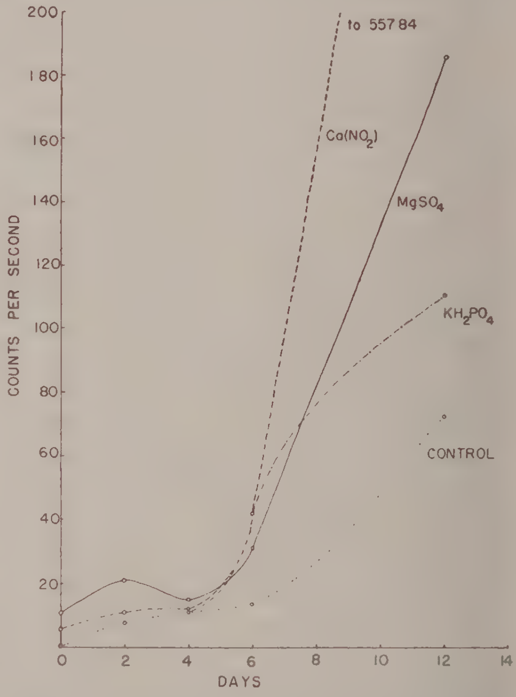

FIG. 10. Relative phytosynthesis in phytoplankton cultures of Brooks Lake water to which $MgSO_4$, $Ca(NO_3)_2$, or KH_2PO_4 were added on 6 July 1957.

Analysis by Beckman flame spectrophotometer of Brooks Lake water collected in February 1958 indicated that 1.2 ppm of magnesium were present. Since the importance of magnesium as a limiting factor declined towards the end of the summer (Fig. 12) it is probable that lower magnesium levels or unfavorable cation ratios (Provasoli *et al.* 1954) existed in June and July. Turbidimetric determinations (American Public Health Association *et al.* 1955) gave 7.6 ppm sulfate. The addition of sulfate as $CaSO_4$,

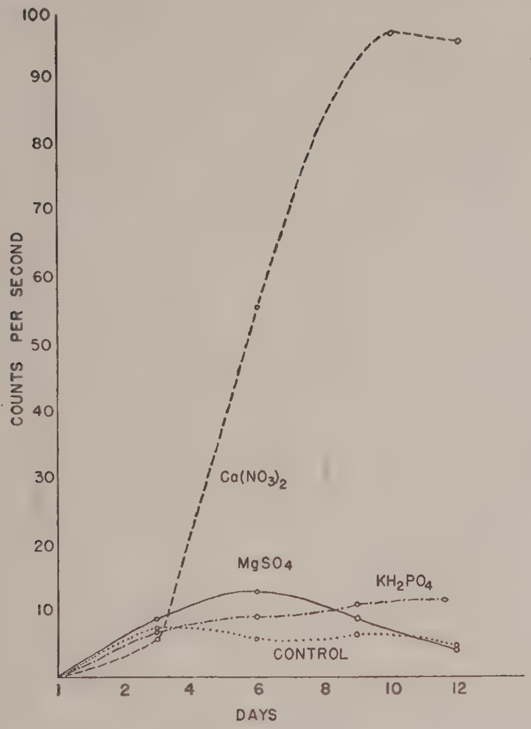

FIG. 11. Relative effect of nutrients on photosynthesis in pure cultures of *Ankistrodesmus falcatus* grown in Millipore filtered Brooks Lake water 31 July 1957.

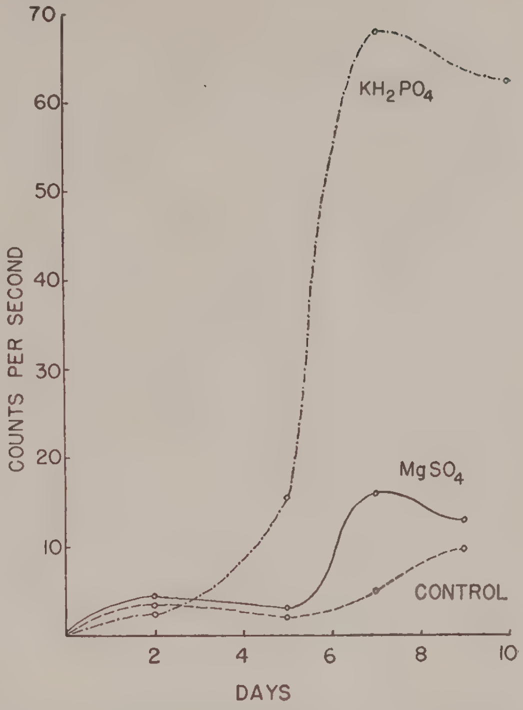

FIG. 12. Relative rates of photosynthesis in cultures of Brooks Lake phytoplankton to which $MgSO_4$ or KH_2PO_4 were added on 16 August 1957.

Na_2SO_4, and $MnSO_4$ in all possible combinations to water taken from Brooks Lake in February 1958 was stimulating to growth, but unless nitrate was provided, this stimulation was short lived.

To determine the relative importance of magnesium in different parts of the lake, surface water was collected at Stations I, III, and IV on 22 July. Each sample was subsequently divided into three 2-liter cultures. Because KH_2PO_4 and $Ca(NO_3)_2$ were also fairly consistent in initiating increases in the rate of carbon fixation above that of the control they were added together with Na_2CO_3 in two of the three cultures from each station. $MgSO_4$ was then added to one of these. The third was maintained as a control. A high rate of productivity in cultures was attained by the addition of $MgSO_4$ when other nutrients were not allowed to become limiting (Fig. 13). The deficiency of magnesium although evident at all stations decreases somewhat in the direction of the lake's main tributary.

The addition of $MgSO_4$ to a single culture of Naknek Lake water did not produce an increase in carbon fixation. With Lake Becharof water, however, $MgSO_4$ gave the highest rate of photosynthesis in the culture experiment conducted on 23 August.

To be certain that the addition of $MgSO_4$ or $Na_2C^{14}O_3$ to the cultures was not initiating the uptake of carbon by ion exchange mechanisms other than photosynthesis (*e.g.* by absorption into outer or apparent free space; Kramer 1957) an oxygen production experiment was run in addition to the regular maintenance of dark bottle controls with C^{14} experiments. Net O_2 production over a five-day period with 0.0, 2.5, and 5.0 microcuries of $Na_2C^{14}O_3$ added, was 0.72, 0.70, and 0.73 ppm of O_2 respectively. In a fourth sample 5.4 ppm of $MgSO_4$ produced 1.3 ppm of oxygen.

As a final check on the limiting nature of $MgSO_4$ in Brooks Lake, the same wire spreaders that were used for suspending duplicate samples for measuring experimental error in the regularly scheduled lake experiments were utilized to determine if there was a significant difference in C^{14} uptake between duplicate samples of lake phytoplankton at Station I. Because of the difficulty of assuming randomness even in dilute plankton populations, a non-parametric test (Wilcoxon Matched Pairs Signed Ranks Test; Siegel 1956) was utilized. The high efficiency (95%) with small samples made this test an excellent statistical treatment for these data.

When the Wilcoxon sum (10) was found to be well below the .05 level of significance (Table 6), the null hypothesis (H_0) was accepted and parallel samples were again taken. To one of each pair, 6 ppm of the nutrient being tested were added together with $Na_2C^{14}O_3$. The other, the control, was inoculated only with $Na_2C^{14}O_3$. These pairs were re-

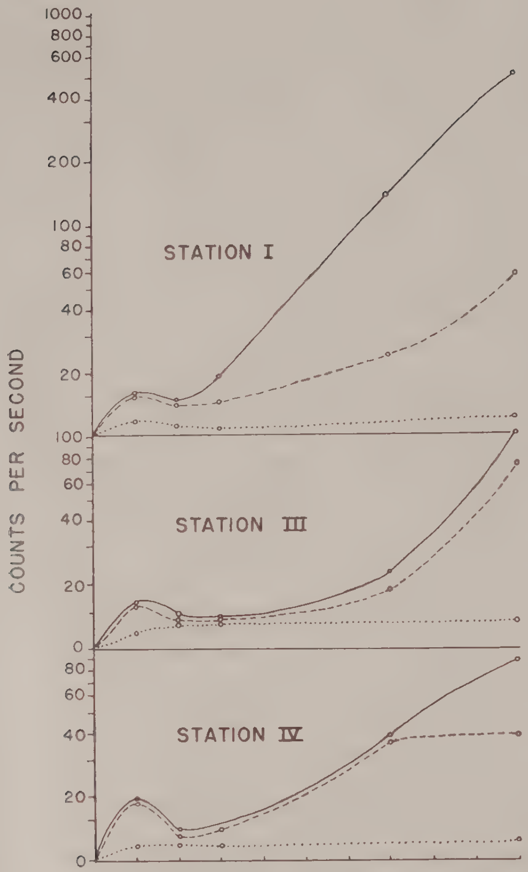

FIG. 13. Relative importance to photosynthesis of $MgSO_4$ in Brooks Lake cultures from Stations I, III, and IV. Solid line: $MgSO_4$, $Ca(NO_3)_2$, KH_2PO_4, and $Na(CO_3)_2$ added. Broken line: all of above nutrients added except $MgSO_4$. Dotted line: control.

suspended at meter intervals from 0 to 5 m for 4 hrs of incubation; then their contents were filtered. This rapid bioassay technique had the advantage of measuring the immediate change in carbon fixation initiated by the addition of specific nutrients at a variety of depths without allowing time for population shifts, which, although not detected in the cultures, might conceivably have occurred in the nannoplankton.

TABLE 6. Relative rates of C^{14} assimilation (count/second) of algae from duplicate samples suspended at Station I. Decision: Accept H_o.

Depth in meters	0	1	2	3	4	5
Sample A.......	2.21	1.68	1.11	3.26	2.01	1.80
Sample B.......	1.58	2.10	1.00	2.94	2.49	1.96

Carbon uptake increased at each depth of incubation in all samples to which 6 ppm of $MgSO_4$ had been added. On a single end-test basis, the Wilcoxon sum of 0 is significant at the .025 level (Table 7).

TABLE 7. Relative rates of C^{14} assimilation (counts/second) of algae from samples of Brooks Lake water suspended at Station I with and without $MgSO_4$ added. Decision: Reject H_o.

Depth in meters	0	1	2	3	4	5
Control........	2.30	1.73	1.84	1.72	2.12	2.34
$MgSO_4$ added...	2.62	2.85	2.09	2.13	2.52	2.96

Calcium nitrate did not produce very significant increases in growth until July. In the culture started on 6 July (Fig. 10), the deficiency of this nutrient was not pronounced until the fourth day when the culture carrying an addition of $Ca(NO_3)_2$ began a rapid increase in rate of carbon assimilation. Twenty-five days later the lack of this nutrient in the lake water was even more pronounced as evidenced by the pure culture (Fig. 11) started on 31 July. The second major green algae pulse in the lake was evident at this time. The response to the addition of $Ca(NO_3)_2$ resembles the preliminary laboratory experiment with *Scenedesmus quadricauda* (Fig. 8).

Unfortunately the only nitrogen determinations that reagents were available for during the field season were for nitrite rather than the more stable and preferable nitrate. The relationship between ammonia, nitrate, and nitrite is apt to be unstable, although nitrate values are likely to be higher. The nitrite values are included in this study because they appear to show a relationship between the available nitrogen in the lake and results of culture experiments. The bioassay technique provides the best basis for assessing nitrogen deficiency.

It is of interest that in the single culture experiment in late August utilizing Naknek Lake water with its natural phytoplankton population, the only nutrient that significantly stimulated carbon assimilation above that of the control was $Ca(NO_3)_2$. At this time nitrite nitrogen values for the lake were appreciably higher than they were in Brooks Lake. The same experiment with Lake Becharof water on 15 July and 23 August showed only a slight photosynthetic increase in July by the addition of $Ca(NO_3)_2$, but in August the stimulating effect of this nutrient was very marked. Lake Becharof nitrite nitrogen for 23 August was at a level above the mean Brooks Lake determination for the same day.

Rodhe (1948), using *Ankistrodesmus falcatus*, found $Ca(NO_3)_2$ to be a better source of nitrogen for this organism than NH_4Cl and recommended 29.4 mg $Ca(NO_3)_2$ per liter as the lowest level for achieving optimum growth. Only 6.1 mg per liter were used in the Brooks Lake study.

In Brooks Lake water there was a decrease in nitrogen, measured as nitrite, during August and early September (Figure 14), concomitant with the deficiency noted in the pure culture experiment (Fig.

12). As already mentioned, in reference to the $MgSO_4$, Brooks Lake water collected in February and used in pure culture experiments in the laboratory gave elevated rates of production when nitrate was added in combination with any one of the following: calcium, magnesium, or sodium. Cultures of *Ankistrodesmus falcatus* to which the three foregoing cations were added individually soon turned from green to yellow with a decrease in rate of photosynthesis. When nitrate was added to these cultures they recovered. This clearly demonstrated that nitrogen was the deficient element.

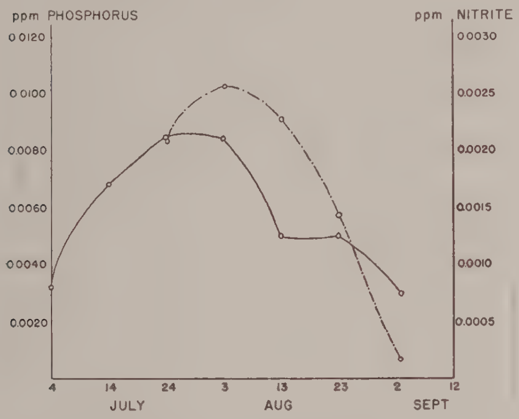

FIG. 14. Average seasonal variation (mean of 0 and 5 meters Station I) of nitrite nitrogen (solid line) and phosphorus (broken line) in Brooks Lake.

With the advent of a new limiting factor in the July cultures, it seemed advisable to repeat the experiment *in situ* at Station I. This time $Ca(NO_3)_2$ instead of $MgSO_4$ was added to one of each of the parallel samples (Table 8). Again utilizing the Wilcoxon Matched Pairs Signed Ranks Test, the increase in carbon assimilation initiated by the addition of $Ca(NO_3)_2$ gives a significant Wilcoxon sum of 1.0 (.05 level = 2.1, .025 level = 0).

TABLE 8. Relative rates of C^{14} assimilation (counts/second) of algae from samples of Brooks Lake water suspended at Station I with and without $Ca(NO_3)_2$ added. Decision: Reject H_o.

Depth in meters	0	1	2	3	4	5
Control........	5.11	7.24	7.17	4.46	3.11	3.47
$Ca(NO_3)_2$ added.	6.31	9.25	7.04	6.03	3.37	5.40

Phosphorus, as KH_2PO_4, although a consistent stimulant to culture growth throughout the summer (Figs. 9, 10, and 11), did not increase the photosynthetic rate in the cultures to the extent that $MgSO_4$ and $Ca(NO_3)_2$ did until middle August (Fig. 12). This corresponded to a relatively high blue-green algae population. An environmental decline in phosphate is in close agreement with culture results. Despite a very low potassium level of 0.94 ppm the addition of potassium as K_2SO_4 to pure cultures did not produce a significant photosynthetic increase.

In Lake Becharof, KH_2PO_4 was the most conspicuous stimulating nutrient in the July experiment. The August cultures of Lake Becharof water did not demonstrate this deficiency, and water analysis at this time showed phosphorus to be at a higher level than in Brooks or Naknek Lakes.

It is common knowledge to aquatic biologists that a large percentage of nutrient material, both organic and inorganic, is lost to the ecosystem by deposition as bottom sediment or by binding in aquatic plants (*e.g.* Hutchinson & Bowen 1950; Hayes *et al.* 1952). Under natural conditions no large-scale release of nutrients occurs unless the oxidized layer of the surface muds disappears (Mortimer 1949). Sedimentation, as in Danish fiords, can be assumed to take place at a faster rate than regeneration (Grøntved & Steemann Nielsen 1957). The recirculation of nutrients freed for reutilization in the system by decomposition is accomplished by eddy diffusion or by overturn in spring and fall. Mechanical agitation (Zicker *et al.* 1956), artificially turning over a lake (Hooper *et al.* 1953), or introduction of compressed air (Schmitz & Hasler 1958), has been suggested as a possible means of increasing the efficiency of the system.

While using SCUBA equipment to inspect the shelf area of Brooks Lake, the author noted that clouds of bottom sediment billowed up as he walked along the bottom. The extremely fine texture of the superficial bottom deposits suggests that mechanical resuspension might easily be achieved if it could be demonstrated that release of soluble nutrients in such bottom material would indeed be beneficial to the metabolism of the lake.

In Brooks Lake, analysis of sediment extract indicated that it contained .062 ppm of phosphorus compared to the lake's .0057 ppm. It also had .023 ppm of nitrite in contrast to the lake's .0012 ppm, and 6.0 ppm more SiO_2 than the lake water. Additions of 1% and 2% by volume of this extract to cultures of Brooks Lake water increased the rate of photosynthesis appreciably (Table 9).

TABLE 9. Assay with C^{14} of the nutrient contribution of bottom sediment extract to cultures of Brooks Lake phytoplankton, in counts/second.

Amount of extract added	DAYS				
	1	2	5	7	11
0% (Control).........	3.63	6.50	5.81	2.56	3.47
1%..................	6.17	8.64	5.98	4.56	..
2%..................	9.17	10.28	9.60	6.84	5.32

DISCUSSION

The importance of lake basin morphometry in influencing lake productivity has received considerable attention since the pioneer work of Thienemann

(1927) and Naumann (1929). Because morphometry affects temperature, thermal and chemical stratification, and dilution and circulation of nutrients, mean depth, as the best indicator of morphometry, has been suggested as a dominant factor in productivity (Rawson, 1952). The extreme variability between lakes precluding any sharp delineation between types has, however, led Larkin & Northcote (1958) to conclude that only the total dissolved solid content could be used as an index of production in their studies.

The information gained from the Brooks Lake studies indicates that, if the productivity of the water alone is considered, the quantity and quality of replenished nutrients by the inflow of tributary streams is a much more important factor than depth. Important considerations in this respect, however, are the benthic development in the littoral zone which would certainly increase the productivity on a surface area basis and antimetabolites which might cause antagonistic interactions between plankton and sessile algae (Jorgensen 1956).

Traditionally the productivity per unit of surface area has been used for comparing different water bodies. On this basis, as in the comparison of Brooks and Naknek lakes, a long euphotic zone may compensate for a lower production per unit volume. There can be little doubt, however, that zooplankton or fish can feed at a faster rate if their food supply is concentrated. Richman (1958) has demonstrated an increase in net efficiency of young production (from 52.08 to 70.46%) by *Daphnia pulex* with increase in the concentration of food supply. Since the food levels he used were well above those encountered in Brooks Lake, higher phytoplankton densities may support a faster rate of zooplankton production. I would expect to find a significantly larger average size of red salmon migrating from Naknek Lake compared with those migrating from Brooks Lake. Supporting this speculation is the recent work (Nelson 1958) on the relationship between photosynthesis and growth of the juvenile red salmon in Bare Lake.

Eicher & Rounsefell (1957), working from fishery statistics, crude soil tests, chemical analyses of lake water, plankton production, and tree growth rings, have suggested that lake fertility may have been significantly increased in the lakes that received volcanic ash during the eruptions of 1912 and 1913. This is especially pertinent to the discussion because Brooks and Naknek Lakes were the only ones on the peninsula thought to have received the ash. Martin (1913) reported that the ash fall extended only as far west as Brooks Lake and the Iliuk arm of Naknek Lake. This reached a maximum thickness of 20 in., and, although covered by a thin layer of humus, is still clearly visible in the area when a shallow excavation is made.

Perhaps the greatest weakness in considering the pumice and ash as a nutrient source is evident from its chemical composition. Griggs (1920), who investigated the recovery of vegetation at Kodiak, makes rather a strong argument of this. He points out the basic difference between this geologically fresh, acid ash and the lava of the Columbian region and further notes that the former has practically the same composition as pulverized granite. He goes on to state that the widespread idea that luxuriant growth of vegetation was due to some fertilizer in the ash was erroneous. Griggs attributes recovery of vegetation to mulching and reduced competition. Attempts at growing wheat in the ash failed, as death ensued as soon as the nutrients stored in the seed were exhausted.

Analysis of the ash compared with the composition of average igneous rock (Pettijohn 1957), showed the latter to be higher in almost every element except silicon. White pumice, hurled out by the eruption, was composed of rhyolitic magma with a silica content of 75%. The high concentration of this important element (Lund 1950) in Brooks and Naknek Lakes is in sharp contrast to Lake Becharof whose watershed did not receive the volcanic pumice or ash. The important water soluble salt potash (K_2O) was especially low in the ash and in Brooks Lake. Griggs (1919) also noted that rankest growth of *Calamagrostis langsdorfii* occurred where evaporation was evidently concentrating the meager salts.

The greatest deficiency in the ash from the standpoint of plant growth, however, was nitrogen (Griggs *ibid.*). The first plant invader of the ash was the lupine (*Lupinus nootkatensis*) which has its own nitrogen-fixing bacteria. Shipley (1919a), chemist for the 1917 Katmai expedition, noted that the high ferrous sulfate content of the ash was not only directly injurious to plant growth, but also inhibited the action of nitrifying bacteria, thereby indirectly reducing the supply of an essential element.

The sub-optimal level of nitrogen in Brooks Lake evidenced by a number of culture experiments during July and August is of special interest since meteorological and geological evidence from the region are in good agreement with these findings. Although the primary source of nitrogen is from the atmosphere, Hutchinson (1957) concluded that in most lakes the origin of fixed nitrogen is to be found in the soils of the drainage basin. It is worth noting at this point that atmospheric nitrogen is not utilized by most algae as is ammonia or nitrate (Kratz & Myers 1955). Shipley (1919b), who was more than casually interested in the nitrogen problem in this area, made numerous determinations for the ammonia and the nitrous nitrogen in the rainwater of southwestern Alaska. Using Nessler's reagent, he found an almost entire absence of ammonia in the rainfall of this region in striking contrast to similar measurements made at about the same latitude in Europe. His highest value was 0.015 ppm NH_3 as compared with the lowest value observed in Scotland of 0.44 ppm. He found nitrate nitrogen in the rainfall along Shelikof Strait from August to September averaged only 0.0018 ppm and noted that nitrites were not transformed to nitrates.

Nitrogen fixation by algae (blue-green) has been recognized for some time (Fogg 1951, William & Burris 1952) and has been demonstrated to increase the yields of rice fields (Watanabe 1956). The lower phosphorus level in the lake in late August might reflect a higher requirement by nitrogen-fixing organisms. The carcasses of spawned-out salmon might also provide a significant amount of nitrogen and phosphorus if the escapement is of great size (Nelson & Edmondson 1955). Unfortunately most of this contribution comes at a time of rapidly declining light intensity and the normal nutrient recirculation by the fall overturn.

The nitrogen contribution of spring or melt water would appear negligible, as Shipley (1919b) commented that it was not necessary to prepare distilled water because of the almost total absence of either nitrous nitrogen or ammonia nitrogen in the spring and creek waters of the district as well as water obtained from melting snow. While the volcanic ash in question contains less than 1% of the nitrogen found in cultivated soil, the tundra of the region has a total nitrogen content of 43.0 ppm which is appreciably higher than Illinois prairie soils or the black loam of the Red River Valley, which Shipley (1919c) used for comparison. He associated this high nitrogen content with a low rate of nitrification in the cold, shallow tundra soil.

Another soil source of nitrogen which has received attention in recent years (Virtanen *et al.* 1955, Virtanen 1957) and which may have been a factor in Shipley's measurements is the alder shrub (*Alnus*). These plants are abundant in the area and have nitrogen-fixing bacteria in root nodules. Although some of the nitrogen leaks directly into the soil, most is deposited in the leaves, which, falling to the ground, add to the soil annually as much as 140 lbs of nitrogen per acre (Lawrence 1958). The possible contribution of alders to lake fertility is certainly worthy of further investigation.

From the above it would appear that the most important source of nitrogen in the area may be from such streams as Headwater Creek, which have their source in the tundra and alder thickets. This hypothesis finds support in the increase in productivity towards the tributary end of the lake as well as in the chemical analysis summarized in Table 5. On 22 July (after a 0.30 in. rain on 21 July) the nitrite nitrogen at Station IV was over twice the average at the other three Brooks stations measured the following day. Thus it would appear that rainfall soaking through the nitrogen rich tundra before entering tributary streams may be a significant factor in the lake fertility of the region. In Brooks Lake, as observed in the sea (Ketchum 1947, Steemann Nielsen 1958), the rate of replenishment of nutrients, rather than the concentration at any given time, determines the fertility of the environment.

Recently sulfate has been found to be a limiting factor in Lake Victoria, Africa (Fish 1955). Even without the chemical analyses and experimentation by addition of sulfate in various forms, the geology of the Alaska Peninsula and analysis of the ash might well suggest a deficiency of magnesium rather than sulfate in this region. Average igneous rock contains almost 3.5% magnesia (MgO). The ash that blanketed the area discussed contained less than 0.5%.

One thing that the eruption certainly did contribute to the area was sulfate. Following the eruption, rain containing high concentrations of sulfuric acid fell over large areas of Alaska (Griggs 1917). As far away as Prince William Sound, 300 mi (483 km) to the east, concentrations were high enough to burn the flesh. Even before the eruption, however, Spurr (1898), in a reconnaissance in southwestern Alaska, noted precipitates of iron and sulfur in hot springs of the Katmai pass. Thawing has been noted in upper Naknek Lake (the Iliuk arm) with air temperatures of 15° F (—9.6° C). This was also considered indicative of hot springs by early explorers (Griggs 1922). Depth was perhaps more important.

Magnesium, occupying the center of the chlorophyll molecule, is essential for both plant growth and chlorophyll formation. Experimental increase of magnesium concentration in Chlorella cultures, even at levels which do not appreciably increase the chlorophyll content, results in an increase in photosynthetic rate (Hill & Whittingham 1955). Like potassium, magnesium has long been recognized as a necessity for life but has not been considered as a limiting factor for phytoplankton development in lakes (Rodhe 1948).

After converting the extensive ionic water analysis of Lohammar (1938) to percentages of equivalents, Rodhe (1949) found close agreement between these and his own analysis of Swedish lakes as well as with those of the world (Clarke 1924). Cations in Brooks Lake as determined by flame spectrophotometer were converted to percentages of equivalents for comparison with these figures (Table 10). This table illustrates a divergence from the usual concentrations in two respects. First the Ca/Mg ratio is much higher in Brooks Lake and secondly the magnesium-sodium relationship is reversed from the usual. The first is of interest in respect to the work by Provasoli *et al.* (1954) which indicates that below monovalent/divalent ratios of 1.3 the range of favorable Ca/Mg ratios for growth of *Synura* sp. is restricted. In contrast the above-mentioned workers found *Fragilaria capucina* does well below this level. The diatom predominance in Brooks Lake is therefore in accord with a monovalent/divalent ratio of 0.31. The second is of interest in relation to the culture work. Magnesium, demonstrated to be very stimulating to phytoplankton growth during much of the season, is less available for plants in the presence of increased quantities of sodium or potasium (Leeper 1952).

It would appear from the evidence at hand that although potassium uptake by cells is independent of the presence or the absence of sodium (Scott & Hayward 1954), the already low magnesium level in

TABLE 10. A comparison of cation percentages of equivalents.

Cation	Entire world (Clarke 1924)	Brooks Lake	Uppland, 1-21 (Lohammar 1938)
Ca^{++}	63.5	63.9	67.3
Mg^{++}	17.4	12.7	16.9
Na^{+}	15.7	20.3	13.6
K^{+}	3.4	3.1	2.2

comparison to other cations is made less available in Brooks Lake by the presence of relatively higher quantities of sodium. The slightly higher levels of phosphorus and nitrogen evident early in the summer are therefore of limited use to the phytoplankton population. Uptake during this period may represent luxury consumption above the phytoplankton requirements (Gerloff & Skoog 1954). As the levels of nitrogen decline, the relative optimum levels of $MgSO_4$ may also be depressed to the actual level of the environment. This situation was observed in cultures of the fungus *Mucar hiemalis* by Fothergill (1954). He found that with lower NH_4NO_3 concentrations optimal growth was obtained at reduced levels of $MgSO_4$ and that K_2HPO_4 has little influence on this relationship.

Very little published data are available on primary productivity in artic lakes. Those that are available are difficult to compare because of the variety of techniques used. Early studies were made by the oxygen method and were usually reported in terms of gross photosynthesis. This is the case in the measurements near Point Barrow, Alaska, by Comita & Edmondson (1953), and the measurements at Bare Lake before and during fertilization (Nelson & Edmondson 1955). The very limited freshwater work with C^{14} is listed by Lund & Talling (1957).

Before the completion of this study, however, Frey & Stahl (1958) made measurements of primary productivity with C^{14} on 13, 16, 19, and 20 August, 1957 in a pond and a lake on Southampton Island in the Canadian arctic. Although the two measurements in the lake (designated S-7) were made for periods of 20 and 24.5 hours, their daily estimates are of interest for comparison with measurements in Brooks, Naknek, and Becharof Lakes during the same period. After correcting their two measurements at S-7 to $mgC/m^3/day$, it is obvious that the difference between the two was not of significant magnitude to necessitate the inclusion of both in the comparison they made with Imikpuk and Bare Lakes. Since the inorganic carbon used in their calculation was approximately half that present, a corrected figure appears in parentheses. The estimate for $mgC/m^3/day$ is 1.5 (2.9) in S-7, as compared with 1.96 in Brooks Lake on 22 August, 10.42 for Naknek Lake on 19 August, and .63 in Lake Becharof on 23 August. The alkalinity of S-7 was over twice that of the three lakes just compared. Since variations in Brooks Lake with seasonal and meteorological conditions range from well below 1.96 to a maximum of 9.86, there is little point in carrying the comparison further than to note that these lakes were all converting solar energy at a rather low rate in comparison to other lakes of the world (Vollenweider 1956).

If the primary productivity in Brooks Lake continued to follow the light values downward after the last sampling date in October (a not unreasonable assumption), about half of the annual production was measured during the season. On this basis an estimate of productivity for Brooks Lake is about twice that of the Sargasso which Steemann Nielsen & Jensen (1957) estimate at 1 $mgC/m^3/day$, or 50 $mgC/m^2/day$.

Problems in connection with fertilization have been covered by a number of authors (*e.g.* Hutchinson & Bowen 1950, Hasler & Einsele 1948). The experiments reported here provide a feasible approach to the establishment of a rationale for increasing basic productivity, and the C^{14} technique as adapted in these studies provides the fastest and most sensitive means yet devised for assessing nutrient limiting factors in natural waters. The Brooks Lake shelf areas hold a great store of nutrients that might be released by mechanical agitation. Since light is frequently inhibiting in very shallow water the increase in turbidity might be more beneficial than detrimental. If fertilization is to be tried in a lake on a trial basis, it should be done with due respect to the factors actually limiting productivity, and should be balanced so as to supplement, not replace, the contribution of the watershed. The work reported here demonstrates the seasonal variation in these factors as well as marked differences in lakes of the same region. A careful investigation of the plankton nutrient requirements, seasonal changes in these requirements, and the trophic relationships of the consumers in individual lakes is of great importance in future work of this kind.

SUMMARY

1. The C^{14} technique was utilized for both bioassay of nutrient limiting factors and direct measurement of primary productivity in Brooks, Naknek, and Becharof Lakes. The efficiency of counting radioactivity was based on conversion of plankton to CO_2, thereby eliminating problems of geometry and self-absorption.

2. Comparisons of daily photosynthetic rate in Naknek and Brooks Lakes on a unit volume basis indicate a threefold higher rate in the former.

3. When photosynthetic rate is compared on a surface area basis, the difference is small.

4. The euphotic zone in Brooks Lake varied from about 25 m to over 50 m with an average for the season of 46 m.

5. The average primary productivity of Brooks Lake was higher on bright days than it was on cloudy days. The reverse was frequently the case in shallow water where light inhibition was especially evident.

6. The depth of the euphotic zone in Naknek

averaged about 16 m with considerable variation with changes in light and turbidity.

7. The possible relationships of Secchi depth to the euphotic zone are discussed with emphasis on the approximate nature of such comparisons.

8. Comparisons of the four Brooks Lake stations indicate that primary productivity per unit volume at comparable depths consistently increases towards the tributary end of the lake.

9. Comparisons of the primary productivity of Naknek Lake Stations A and B indicate a higher rate at the less turbid Station A.

10. Primary productivity measurements in Brooks Lake compare favorably with variations in total phytoplankton. Phytoplankton and zooplankton abundance both followed the seasonal decline in light energy so evident at these northern latitudes.

11. The sensitivity of the C^{14} technique was demonstrated in the laboratory with a nitrate deficient culture of *Scenedesmus quadricauda*.

12. Magnesium was found to be a limiting factor for phytoplankton production throughout the summer by both culture and *in situ* lake experiments. The relative importance of magnesium decreases somewhat towards the major tributary and also as other nutrients become limiting.

13. Magnesium deficiency was also noted in Lake Becharof in late August.

14. Nitrate deficiency was evident in Brooks Lake cultures in July and August. Results were verified in experiments *in situ*.

15. The single culture experiment in Naknek Lake indicated nitrate deficiency in late August. The Lake Becharof experimental cultures in July showed only slight stimulation with the addition of nitrate; in the August culture, the nitrate addition was considerably more stimulating.

16. Phosphorus, although consistently stimulating to photosynthesis, did not appear as critical as $MgSO_4$ or $Ca(NO_3)_2$ until middle August. An environmental decline was observed at this time. In Lake Becharof, although phosphorus was of primary importance in July, by August environmental levels were above those in Brooks and Naknek Lakes and the cultures derived no measurable benefit from its addition.

17. Brooks Lake bottom sediment extract was very stimulating to cultures of the natural phytoplankton population.

18. A discussion is given on published work related to the problems of primary productivity and fertility in artic lakes.

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Two New Species of *Candacia* (Copepoda: Calanoida) from the Central Pacific, with Notes on Two Other Species[1]

GEORGE D. GRICE[2] and EVERET C. JONES[3]

DURING EXAMINATION of plankton samples collected from the central Pacific Ocean by the Honolulu Biological Laboratory (formerly Pacific Oceanic Fishery Investigations) of the U. S. Fish and Wildlife Service, two species of *Candacia* were found which appear to be undescribed. In addition to describing these two species we present evidence that *Candacia turgida* Wilson is a synonym of *C. truncata* (Dana). We also include a description and figures of *Candacia norvegica* (Boeck), a species apparently rare in the Pacific Ocean.

We wish to acknowledge the help of Dr. Thomas E. Bowman in loaning us type material from the U. S. National Museum, and that of Dr. Paul L. Illg for valuable suggestions during the preparation of the type material and the manuscript.

Candacia pofi new species
Figs. 1–21

LOCALITY AND MATERIALS: 1° 23′ S., 112° 46′ W. (U. S. Fish and Wildlife Service "Hugh M. Smith" cruise 31, station 75-3, Oct. 31, 1955, 200–140 m. depth of tow; 23 females and 6 males). Physical, oceanographic, and other data from this cruise have been published by King, Austin, and Doty (1957).

Type material of *Candacia pofi* has been deposited in the U. S. National Museum as follows: Female holotype (USNM 102730), male allotype (USNM 102731), 22 female paratypes and 5 male paratypes (USNM 102732).

MEASUREMENTS: Measurements were made from a dorsal view along a sagittal plane. The abdomen was supported by a plastic strip to reduce flexion. The copepod, stained with methyl blue and immersed in lactic acid, was mounted under a cover slip supported by plastic strips to avoid distortion due to pressure or a meniscus. The total length was measured from the anterior margin of the head to the ends of the caudal furca. The abdomen was measured from the anterior margin of the genital segment to the ends of the caudal furca. These measurements excluded the telescoped portions of the abdominal segments. The ratios of the lengths of the abdominal segments, however, include the telescoped portions as indicated by dotted lines in the figures. Pertinent measurements and ratios of the cephalothorax and abdomen of the holotype, allotype, 3 female paratypes, and 4 male paratypes are given in Table 1.

DESCRIPTION: In the adult female the cephalothorax (Fig. 1) is slender, being widest at the first thoracic segment. The posterior lateral angles of the thorax are produced into sharp symmetrical processes which reach to a line including 60 per cent of the length of the genital segment (Fig. 3). The genital segment (Fig. 3) is symmetrical in dorsal view, longer than wide and without lateral swellings or processes. The genital pore is situated on a very large protuberance which extends ventrad and caudad. In lateral view (Figs. 2, 4), the posterior margin of this protuberance is approximately continuous with the posterior margin of the genital segment. In ventral view (Fig. 5), the genital protuberance is round with a slight lip at the posterior margin. In the holotype, this lip is slightly asymmetrical. The second abdominal segment (Fig. 3) is asymmetrical in dorsal view, the right margin being convex and the left margin straight. The ventral surface is wrinkled and bears a low process which extends to the left as a lobe with a more or less crenulate margin.

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[1] Contribution No. 131, Hawaii Marine Laboratory, University of Hawaii, with which one of the authors (G. D. G.) was associated. Manuscript received January 16, 1959.

[2] Fellow of the John Simon Guggenheim Memorial Foundation, 1958–59. Present address: Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

[3] Bureau of Commercial Fisheries, Biological Laboratory, Honolulu, Hawaii.

The dorsal surface of the anal segment (Fig. 3) bears a very prominent, broad bifurcate process pointing caudad. The posterior lateral surface of each of the diverging tubercles of this process has a patch of very fine teeth visible under 100× magnification. In the holotype, these tubercles appear to be slightly asymmetrical in size and in details of minute swellings and creases. Examination of paratype material indicates that there is variation in these details and also in the ventral lobe of the second abdominal segment.

The furcal rami (Fig. 3) are longer than wide. The outermost furcal setae are thick and originate high on the lateral margins of the rami. There is a small tooth dorsad of the origin of the middle major seta of each ramus.

The proximal seven segments of the first antennae are thickened. The first segment has three small spines, and segments 2 through 6 have small marginal spines (Fig. 6). It is probable that additional segments had spines which have been lost in the material at hand.

The second antennae are similar to those of other members of the genus. The exopod has six setae plus a minute one; the second endopodal segment is divided into two lobes, the external with six setae plus a minute one and the internal with five setae plus a minute one.

The exopod of the mandibular palpus has five setae; the endopod has six. The mandibular blades (Fig. 7) are composed of a large point and a basal tooth with three points decreasing in length mediad.

The first maxillae are best described by reference to Figure 8.

The second maxillae (Fig. 9) are large and have the form of maxillipeds. The basal segment is composed of four lobes. There is a single long seta on the first lobe with a minute seta at its base, two small setae on the internal margin of the second lobe; and one large spine with a short spine at its base on each of the third and fourth lobes. There are two long spines of about equal length on the second basipodal segment, and the proximal one has a minute spine at its base. Distad of the second basipodal segment are three very long, curved spines, the middle of which is the longest. Three very small bristles arise from the base of the distal spine.

The maxillipeds are reduced in length (Fig. 10). The first segment is about as long as the remaining segments combined and is 1.7 times the length of the second. There is a tubercle on the internal margin of the first segment near the proximal end and a single long seta just distad of the midpoint of that margin. Two slender setae, one twice the length of the other, arise from the junction of the first and second segments. At about the midpoint of the internal margin of the second segment, there is a patch of hair proximad of three setae. The distal end of this segment appears to receive the proximal end of the third so that the second and third each have three setae. Vervoort (1957), in describing *C. maxima,* attributes four setae to the second segment and two to the third. Giesbrecht (1892, pl. 21, figs. 26, 27) indicates that in *C. longimana* Claus the fourth seta is between the two segments but in *C. bispinosa* Claus it is on the third segment. This appendage is usually regarded as having little diagnostic value, but the origin of the fourth seta might add a distinguishing character. The fourth, fifth, and sixth segments have a pair of setae, the distal one in each pair being longer. Distad of the sixth segment are two long setae of almost equal length.

The lengths of the third exopodal segments of swimming feet 1 to 4 (Figs. 11–14) have the following relation to that of their respective terminal spines: 1:1, 2:1, 3:1, and 3:2.

The symmetrical fifth feet (Fig. 15) are long and slender, each ending in two sharp, smooth terminal fingers. The inner finger is about four times the length of the outer finger. There are two external spinous processes located at points about one-fourth and two-thirds of the segment length from the proximal end of the distal segment. There are no internal spines or setae. The penultimate segment bears a single seta, and the ratio of the length of that segment to that of the distal segment is 1:4.6.

Brown pigmentation in the female is restricted to the following structures: the fifteenth segment of the first antennae, the setae of the second antennae and the mandibular palpi, the second segment of the second max-

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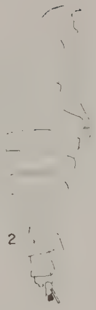
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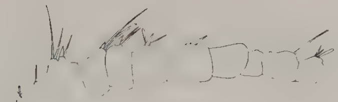
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SCALES

0.1 MM. FIGS. 3-6, 8, 9, 11-15, 18-21

0.05 MM. FIG. 7

1.0 MM. FIGS. 1, 2, 16, 17

0.05 MM. FIG. 10

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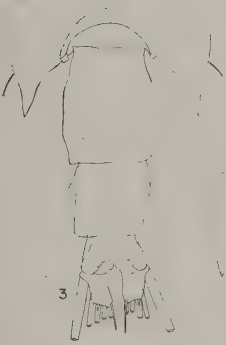
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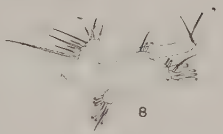
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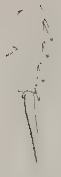
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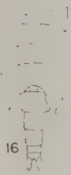
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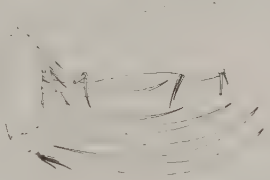
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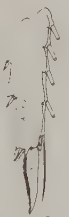
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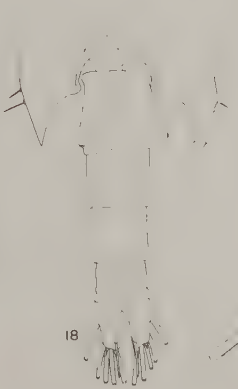
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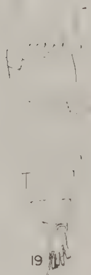
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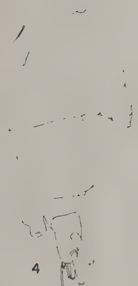
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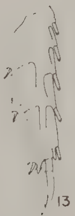
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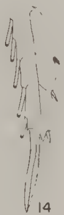
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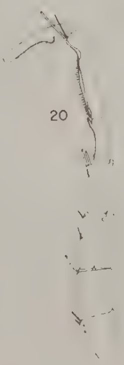
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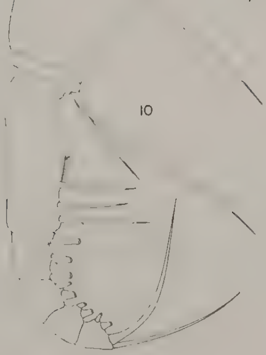
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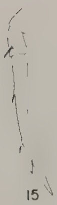
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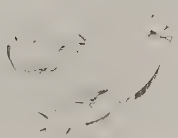
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TABLE 1
TOTAL LENGTHS, CEPHALOTHORAX–ABDOMEN RATIOS, AND ABDOMINAL SEGMENT RATIOS OF *Candacia pofi*

SPECIMENS	TOTAL LENGTH (mm.)	CEPHALOTHORAX–ABDOMEN RATIO	RELATIVE LENGTH OF ABDOMINAL SEGMENTS					
			1	2	3	4	5	Furca
Females								
Holotype	2.30	2.75:1	38	32	16	...	...	14 = 100
Paratype	2.41	2.64:1	42	30	16	...	...	12 = 100
Paratype	2.41	2.55:1	41	32	16	...	...	11 = 100
Paratype	2.36	2.75:1	39	29	17	...	...	15 = 100
Males								
Allotype	2.28	2.52:1	21	21	21	14	9	14 = 100
Paratype	2.21	2.61:1	21	21	21	14	9	14 = 100
Paratype	2.24	2.38:1	21	21	21	14	9	14 = 100
Paratype	2.23	2.54:1	...	...	...	...	...	... ...
Paratype	2.21	2.43:1	...	...	...	...	...	... ...

illae, the third exopodal segments of swimming feet 1 to 4, and the furcal setae.

The pertinent measurements and ratios of the adult males are presented in Table 1. The posterior lateral angles of the male cephalothorax (Fig. 16) are produced into asymmetrical processes. The left is sharp and reaches to the posterior margin of the genital segment. The right process (Fig. 18) is thick and slightly curved inward and reaches to a line including one-quarter of the length of the second abdominal segment. In lateral view (Figs. 17, 19), this right process is thick and truncate with a convex dorsal margin and a concave ventral margin.

The male genital segment (Fig. 18) is asymmetrical with a rounded swelling tipped with a small button on the right side. In lateral view (Fig. 19) the swelling appears as two or three concentric, incomplete circles. The left posterior margin of the genital segment is broken by the genital opening. In the allotype, a canal is visible from the genital opening to a spermatophore (Fig. 18).

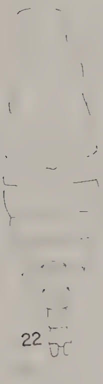
The geniculate right antenna (Fig. 20) is armed with coarse, unequal pigmented teeth on segment 18, fine pectination on segment 17 extending onto the anterior margin of a distal spinous process, and very fine pectination on segment 19. Segments 17, 18, 19, and 20 are separate.

The right fifth foot (Fig. 21) is chelate with the tip of the distal segment reaching slightly beyond that of the penultimate segment. The terminal spine is turned flat against the surface of the distal segment. The left fifth foot is broad and ends in a spatulate segment (Fig. 21).

Pigmentation is similar to that of the female. In addition, the geniculate portions of the right first antenna are heavily pigmented. There is no pigmentation on the right thoracic process or the genital segment.

REMARKS: The female of *C. pofi* resembles *C. cheirura* Cleve (as described by Farran, 1929) in having ventral protuberances on the genital and second abdominal segments, and thick ex-

FIGS. 1–21. *Candacia pofi* n. sp. 1, female, dorsal view; 2, female, lateral view; 3, fourth and fifth thoracic segments and abdomen, dorsal view, female; 4, fourth and fifth thoracic segments and abdomen, lateral view, female; 5, abdomen, ventral view, female; 6, proximal 10 segments of first antenna, female; 7, mandibular blade, female; 8, first maxilla, female; 9, second maxilla, female; 10, maxilliped, female; 11, third exopodal segment of first foot, female; 12, third exopodal segment of second foot, female; 13, third exopodal segment of third foot, female; 14, third exopodal segment of fourth foot, female; 15, fifth foot, female; 16, male, dorsal view; 17, male, lateral view; 18, fourth and fifth thoracic segments and abdomen, dorsal view, male; 19, fourth and fifth thoracic segments and abdomen, lateral view, male; 20, segments 13 through 19, right first antenna, male; 21, fifth feet, male. Figures 1–12 and 15 drawn from holotype; Figures 13 and 14 from paratype. Figures 16–19 and 21 drawn from allotype; Figure 20 from paratype.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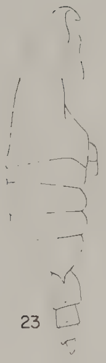
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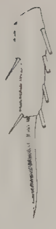
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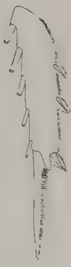
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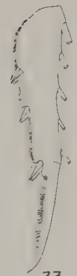
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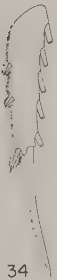
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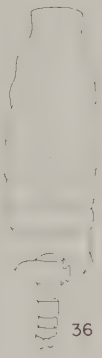
SCALES

0.5 MM FIGS. 22, 23, 36, 37

0.05 MM FIGS. 27, 30, 35

0.1 MM. FIGS. 28, 31-34, 40, 41

0.1 MM. FIGS. 24-26, 29, 38, 39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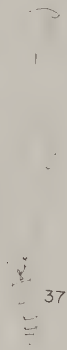
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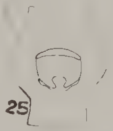
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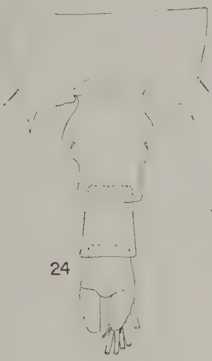
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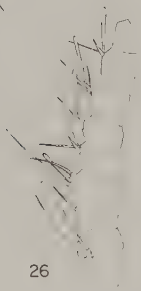
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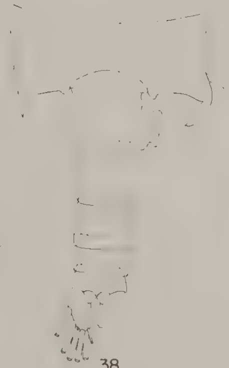
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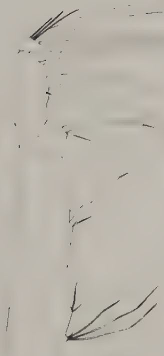
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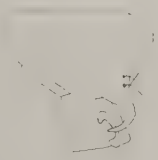
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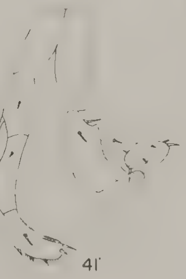
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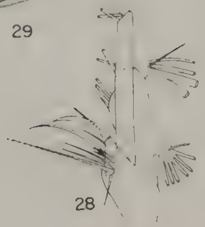
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ternal furcal setae. It can be distinguished from *C. cheirura* by the asymmetry of the abdomen in dorsal view and by the presence of dorsal tubercles on the anal segment. The female resembles *C. armata* Boeck (as described by G. O. Sars, 1903) in having an asymmetrical second abdominal segment. It can be distinguished from this species by the extremely large genital protuberance, the ventral lobe of the second abdominal segment extending to the left rather than to the right, the dorsal tubercles on the anal segment, and details of the fifth feet.

The geniculate antenna of the male *C. pofi* resembles that of *C. armata* Boeck (as described by Sars, 1903), *C. bradyi* and *C. discaudata* A. Scott, *C. bipinnata* Giesbrecht, and *C. cheirura* Cleve in having segments 17, 18, 19, and 20 separate and in having coarse, unequal pigmented teeth on segment 18. *C. pofi* can be distinguished from *C. bradyi* and *C. discaudata* by the produced right thoracic process. It can be distinguished from *C. armata, C. bipinnata,* and *C. cheirura* by the low, rounded genital process in lieu of the sharp spinous process in those species. The name of this species is derived from Pacific Oceanic Fishery Investigations.

Candacia guggenheimi new species

Figs. 22–41

LOCALITIES AND MATERIALS: 26° 25.2′ N., 155° 03.0′ W. (U. S. Fish and Wildlife Service "Hugh M. Smith" cruise 25, sta. 33, Feb. 10, 1954, 200–0 m. depth of tow, 2 females, 4 males); 32° 33′ N., 148° 51.5′ W. ("Hugh M. Smith" cruise 25, sta. 53, Feb. 22, 1954, 200–0 m. depth of tow, 1 male); 23° 56′ N., 157° 31′ W. ("Hugh M. Smith" cruise 30, sta. 112-1, Aug. 27, 1955, 140–0 m. depth of tow, 1 female); 21° 55′ N., 158° 08′ W. ("Hugh M. Smith" cruise 32, sta. 26, Feb. 5, 1956, 200–140 m. depth of tow, 1 female, 1 male); 0° 00′, 149° 38′ W. ("Hugh M. Smith" cruise 47, sta. 29, Oct. 27, 1958, 500 m. depth of tow, 1 female). This species has also been observed in samples collected at the following stations on "Hugh M. Smith" cruise 25 (all 200–0 m. collections): 21° 36.5′ N., 159° 00′ W. (sta. 2, Jan. 16, 1954); 33° 55.7′ N., 164° 58.5′ W. (sta. 11, Jan. 22, 1954); 26° 31′ N., 160° 00′ W. (sta. 26, Jan. 30, 1954); 22° 03.7′ N., 158° 40′ W. (sta. 29, Feb. 1, 1954); 29°-32′ N., 155° 04.8′ W. (sta. 35, Feb. 12, 1954); 32° 30′ N., 154° 59′ W. (sta. 37, Feb. 13, 1954). Physical, oceanographic, and other data for cruise 25 have been summarized by McGary and Stroup (1956) and that for cruise 30 by McGary, Jones, and Austin (1956).

Type material of *C. guggenheimi* has been deposited in the U. S. National Museum. A female from cruise 25, sta. 33, was selected as the holotype (USNM 102733). A male from this station was designated the allotype (USNM 102734). Paratypes are as follows: 1 female, 3 males, cruise 25, sta. 33 (USNM 102735); 1 male, cruise 25, sta. 53 (USNM 102736); 1 female, cruise 30, sta. 112-1 (USNM 102737); 1 female, 1 male, cruise 32, sta. 26 (USNM 102738); 1 female, cruise 47, sta. 29 (USNM 102739).

MEASUREMENTS: All measurements were made in the method described for the preceding species. The total length of five adult females ranges from 1.94 to 2.06 mm. The lengths and cephalothorax–abdomen ratios, based on three of these individuals are: holotype 2.01 mm., 2.9:1; paratypes 1.96 mm., 2.8:1; 2.04 mm., 3.1:1.

The total length of six adult males varies from 1.90 to 2.00 mm. These lengths and the

FIGS. 22–41. *Candacia guggenheimi* n. sp. 22, female, dorsal view; 23, female, lateral view; 24, fourth and fifth thoracic segments and abdomen, dorsal view, female; 25, genital segment, ventral view, female; 26, proximal seven segments of first antenna, female; 27, mandibular blade, female; 28, first maxilla, female; 29, second maxilla, female; 30, maxilliped, female; 31, third exopodal segment of first foot, female; 32, third exopodal segment of second foot, female; 33, third exopodal segment of third foot, female; 34, third exopodal segment of fourth foot, female; 35, fifth foot, female; 36, male, dorsal view; 37, male, lateral view; 38, fourth and fifth thoracic segments and abdomen, dorsal view, male; 39, fourth and fifth thoracic segments and genital segment, lateral view, male; 40, segments 17 through 19, right first antenna, male; 41, fifth feet, male. Figures 22, 23, 27, and 34 drawn from paratype; Figures 24–26, 28–33, and 35 drawn from holotype. Figures 36–39 and 41 drawn from allotype; Figure 40 drawn from paratype.

cephalothorax–abdomen ratios, based on four of these, are: allotype 1.90 mm., 2.91:1; paratypes 1.92 mm., 2.9:1; 1.94 mm., 2.7:1; 2.00 mm., 2.7:1.

DESCRIPTION: The general shape of the adult female is similar to other species of the genus *Candacia.* The head is truncate in dorsal view; thoracic segments 4 and 5 are fused and produced posteriorly into two symmetrical points (Fig. 22). In lateral view (Fig. 23), a small hump is visible on the dorsal surface at the junction of the head and first thoracic segment.

The genital segment is slightly asymmetrical; the lateral swelling on the left side is smaller and somewhat more expanded than that on the right side (Figs. 24, 25). A single dorsal spine is present on each swelling. The abdominal segments and furca have the following proportions (based on holotype): 40, 26, 19, 15 = 100.

The first antennae, when held against the body, reach to about the tips of the furcal rami. The proximal part of the antenna is thickened and consists of seven segments (Fig. 26). Segments 1 through 6 and 8 through 12 have one spine. There are indications that additional segments are furnished with a spine but no perfect antennae were present among the specimens examined.

The second antennae are similar to those of other species of *Candacia.* Basipodal segments 1 and 2 have one seta. Segment 2 of the endopod ends in two lobes. The outer lobe has six large and one small setae. The inner lobe has five large and one small setae and one minute seta proximad of the small one.

The exopod of the mandible apparently consists of four segments, the first three of which are furnished with a single seta. The terminal segment has two setae. The endopod is composed of one segment which is provided with six setae. The basal tooth of the mandible is furnished with two subequal points and a marginal point (Fig. 27).

The first maxillae are best described by reference to Figure 28.

The second maxillae are of large size (Fig. 29). The basal segment has four lobes. There are three long and one very short setae on the first lobe, one long and one short seta on the second lobe, one long and one short spine on the third lobe, and one long and one short spine on the fourth lobe. The second basipod segment has two subequal spines, the proximal one has a minute spine at its base. The endopod is furnished with three spines, the middle of which is slightly longest. In addition there are three bristles on the terminal part of the endopod.

The maxillipeds (Fig. 30) are small. The first basal segment is more than twice as long as the second basal segment. The former has one seta at a point about two-thirds of the segment length from the proximal end and two setae on the distolateral corner. The second basal segment is furnished with three unequal setae and one other seta on the apparent apex. Hair is present on the internal margin of this segment. The five endopodal segments are each furnished with one long and one short seta. The long seta on the terminal segment is somewhat longer than those on the other endopodal segments.

The third exopodal segments of swimming feet 1 to 4 are shown in Figures 31–34. The relative lengths of these segments to their respective terminal spines are as follows (based on several specimens): 1:1, 1:0.8 (estimate), 1:0.6, and 1:1.

The fifth feet are symmetrical and each terminates in one long stout finger and one short spinous process (Fig. 35). The former is about three times longer than the latter. The finger has several rounded serrations distally, and the spinous process is finely serrate. The external margin of the segment has two spinous processes. The internal margin bears two subequal setae in all observed specimens except one ("Hugh M. Smith" cruise 47, sta. 29-1) which has three internal setae on one foot.

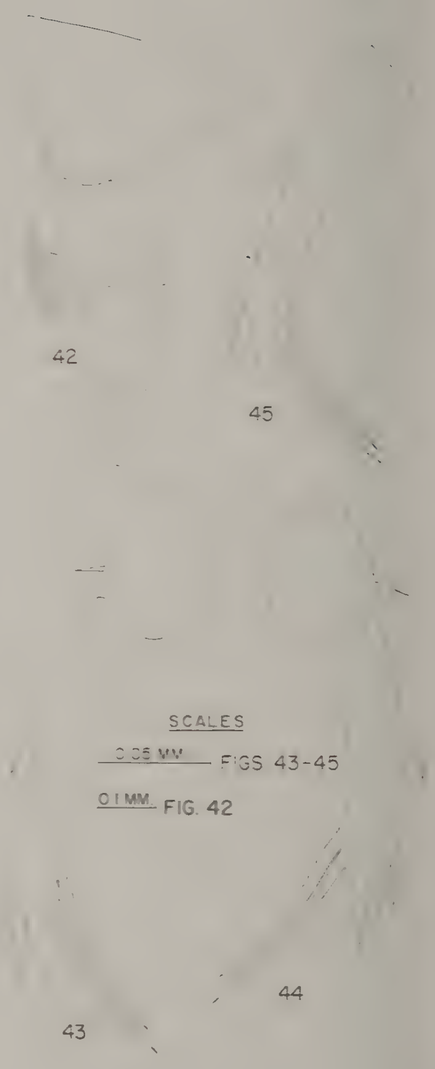
The following appendages of the preserved holotype are pigmented: the distal 18 segments of the first antennae, the distal spinelike claw on the first inner lobe of the first maxillae, portions of the first basipod segment and the distal five spines of the second maxillae, basipodal segments 1 and 2 of the first four pairs of swimming feet, and the terminal finger and spinous process of the fifth pair of feet. The female collected on "Hugh M. Smith" cruise 47, sta. 29, has additional pigmentation as follows: the distal 20 segments of first antennae, the spines on lobes 3 and 4 of the second maxillae, much of both rami of swimming feet 1 to 4 including several setae on the second and third exopodal segments and second endopodal segment, and the first basipodal segment of the fifth pair of feet.

The adult male (Figs. 36, 37) is slightly smaller than the female. The right posterior lateral process of the fifth thoracic segment is produced posteriorly and curved inward in dorsal view (Fig. 38). It reaches to the middle of the protrusion on the genital segment. In lateral view, the thoracic process has a decided upward bend (Fig. 39). The genital segment has a bilobed protrusion arising from near the posterior end of the right margin (Fig. 38). The abdominal segments and furca have the following ratios (based on three specimens): 22, 24, 20, 13, 9, 12 = 100.

Segments 17, 18, 19, and 20 of the right first antenna (Fig. 40) are separate, with 17, 18, and 19 toothed. The nearly uniform teeth on segment 18 are coarser than those on segments 17 and 19. The fifth feet are shown in Figure 41.

The following body parts and appendages of the male are pigmented (based on examination of several specimens): segments 17 to 25 of the right antenna, the distal 17 segments of the left antenna, the process on the right corner of the fifth thoracic segment, the clawlike spine on the distal part of the first inner lobe of the first maxillae, portions of the first basipod and spines on lobes 3 and 4 and the five large distal spines of the second maxillae, basipodal segments 1 and 2 of swimming feet 1 to 4.

REMARKS: The female of *C. guggenheimi* superficially resembles *C. longimana* Claus. The spines on the dorsal surface of the genital segment, the structure of the fifth pair of feet, and the somewhat smaller size of this species readily distinguish it from *C. longimana.* The bilobed protrusion on the genital segment and the structure of the fifth feet serve to distinguish the male. This species is named for the late Simon Guggenheim, one of the founders of the John Simon Guggenheim Memorial Foundation.



FIGS. 42—45. *Candacia truncata* (Dana). 42, fourth and fifth thoracic segments and abdomen, left lateral view, female, showing cement mass attached to genital segment. 43, 44, unlike fifth feet, female, from same specimen; 45, fifth foot, female, with serrated external spinous processes, from another specimen.

NOTES ON TWO OTHER SPECIES

Candacia truncata (Dana)
Figs. 42–45

Candace truncata Dana, 1849, Proc. Amer. Acad. Arts Sci., 2: 24.

Candacia truncata Giesbrecht and Schmeil, 1898, Das Tierreich, 6, p. 130; auct.

Candacia turgida Wilson, 1950, U. S. Natl. Mus. Bul. 100, 14(4): 183–184. New synonomy.

In the course of examining plankton samples we have encountered numerous individuals of a species which appears to agree with the description of *C. turgida* Wilson (1950). We believe, however, that these specimens, as well as *C. turgida,* are identical with *C. truncata* (Dana).

The pigmented process on the ventral side of the female genital segment (shaded portion of Fig. 42), which Wilson considered to be a protrusion of that segment, appears to be a mass of cement associated with a spermatophore. In most of the samples examined there were some females with this mass and others without. Furthermore, the mass can be removed quite easily with a needle. Tanaka (1935) presented a figure of a female *C. truncata* showing such a mass adhering to the genital segment.

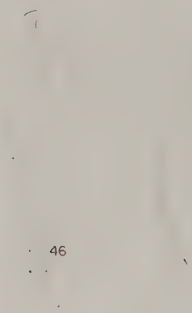
Wilson's figure of the female fifth feet (1950: pl. 22, fig. 308) of his *C. turgida* apparently is not complete in detail. Dr. Thomas E. Bowman has kindly sent us a sketch of the fifth feet from one of the syntypes of this species. His sketch and the numerous fifth feet examined from our material agree in the structure of the large terminal finger. The external margin of this finger in all specimens examined and in Dr. Bowman's sketch is finely serrate along most of its length. The distolateral and two external spinous processes are, however, somewhat variable. In some specimens the distolateral spinous process has one or two relatively large teeth on the internal margin as figured by Giesbrecht (1892). One has a single external tooth opposite two internal ones; another has seven small internal teeth. In some specimens the feet are asymmetrical, being unequal in length and with unlike dentition on the distolateral spinous process. One specimen has four teeth on one foot and two on the other. In yet another, this process is toothed on one foot and smooth on the other. Figures 43–45 show some of the variations of the fifth feet of the female *C. truncata* from the central Pacific. Typical males of *C. truncata* have also been observed in our collections. Specimens of this species were obtained in the following localities: 22° 03.7′ N., 158° 40′ W. ("Hugh M. Smith" cruise 25, sta. 29, Feb. 1, 1954, 200–0 m. depth of tow); 0° 00′, 149° 36′ W. ("Hugh M. Smith" cruise 47, sta. 30, Oct. 27, 1958, surface collection). Seven females from 23° 55′ N., 157° 31′ W. ("Hugh M. Smith" cruise 30, sta. 112-2, Aug. 27, 1955, 49 m. depth of tow) have been deposited in the U. S. National Museum (USNM 102740).

Candacia norvegica (Boeck)
Figs. 46–65

The distribution of *Candacia norvegica* (Boeck) in the North Atlantic has been summarized by Farran (1948). Sewell (1932) described a variety *tropica* from the Indian Ocean. In his reports on the Carnegie and Albatross collections, Wilson (1942, 1950) recorded *C. norvegica* from many stations in the tropical and temperate Pacific Ocean. In a

FIGS. 46–65. *Candacia norvegica* (Boeck). Figures 46–62 refer to Pacific specimens. Figures 63–65 to Atlantic specimen. 46, female, lateral view; 47, abdomen, dorsal view, female; 48, lateral view of left genital spinous process; 49, lateral view of right genital spinous process; 50, 51, mandibular blades from one individual female, showing unlike basal teeth; 52, first maxilla, female; 53, second maxilla, female; 54, fifth feet, female, with two external spinous processes on each foot; 55, fifth feet, female showing three external spinous processes on one foot and two on the other; 56, male, dorsal view; 57, male, lateral view; 58, fourth and fifth thoracic segments and abdomen, dorsal view, male; 59, genital segment, ventral view, male; 60, fourth and fifth thoracic segments and genital segment, right lateral oblique view, male; 61, segments 17 through 19, right first antenna, male; 62, fifth feet, male; 63, abdomen, dorsal view, female; 64, left genital spinous process; 65, right genital spinous process. Figures 47–48 and 54 are from Pacific female 2.96 mm. total length, all others of Pacific female are from specimen 2.80 mm. total length.

SCALES
1.0 MM. FIGS. 46, 56, 57
0.05 MM. FIGS. 48-51, 64, 65
0.1 MM. FIGS. 52, 54, 55, 60-62
0.1 MM. FIGS. 47, 53, 58, 59, 63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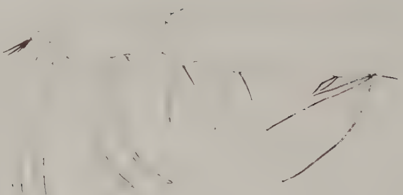
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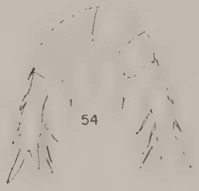
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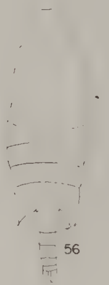
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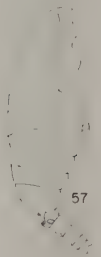
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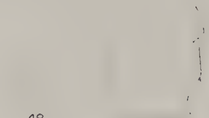
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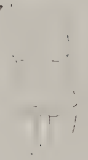
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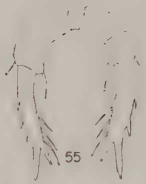
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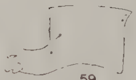
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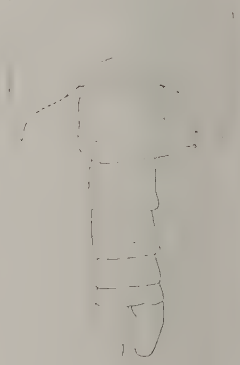
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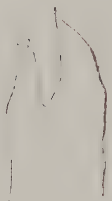
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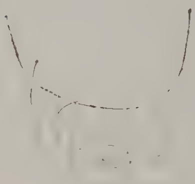
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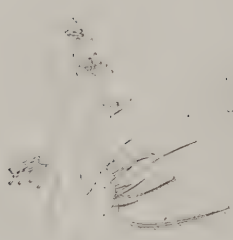
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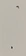
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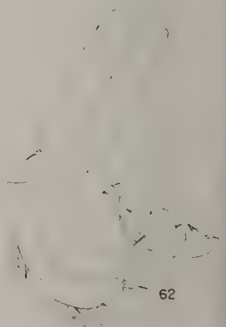
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TABLE 2

COMPARISON OF FEMALE *Candacia norvegica* FROM GEORGES BANK, THE PACIFIC, AND VARIETY *tropica*

SOURCE	TOTAL LENGTH* (mm.)	CEPHALOTHORAX–ABDOMEN RATIO*	ABDOMEN RATIO = 100 SEGMENT NUMBER 1	2	3	Furca
Georges Bank (USNM)	3.24	2.89:1	45	24	18	13
Pacific	2.96	2.66:1	45	24	17	14
Pacific	2.80	2.83:1	44	22	19	15
Variety *tropica* (Sewell, 1932)†	2.28	2.92:1	43	25	19	13

* Includes telescoped portion of abdominal segments of the specimens from Georges Bank and from the Pacific. Sewell's data used for *tropica.*

† Sewell apparently reversed the figures for the ratio of the anal segment and furca. Measurement of his figure of the abdomen shows that the length of the anal segment exceeds that of the furca.

recent paper, Fleminger and Bowman (1956) have reported that Wilson's determinations were incorrect and that *C. norvegica* was not present in any of the Carnegie and Albatross material in the U. S. National Museum. The only other mention of this species from the Pacific appears in Tanaka's (1953) list from the Izu region off southern Japan. Because no description or figures have been given of Pacific specimens and because of the apparent rarity of the species in that ocean, we are including a description based on two females and one male collected in the central North Pacific. These specimens were collected at 37° 43.9′ N., 165° 0.5′ W. ("Hugh M. Smith" cruise 25, sta. 13, Jan. 24, 1954, 200–0 m. depth of tow, 2 females and 1 male) and have been deposited in the U. S. National Museum (USNM 102741).

We have compared our specimens with Atlantic *C. norvegica* collected south of Georges Bank (northwest Atlantic) and loaned to us by the U. S. National Museum, with Sewell's description of *tropica,* and with Sars' (1903) redescription of *C. norvegica* based on specimens from the Norwegian Sea. Differences in the details of the lateral spines of the female genital segment were found. Sars implied in his description that these spines are simple and single pointed. Variety *tropica* Sewell is stated to have bifid spines on both sides. Our Pacific specimens agree with *tropica* in this respect, but the spines are somewhat smaller (Figs. 48, 49). The Georges Bank specimen examined by us has a slightly bifid tip on the left spine and a simple spine on the right (Fig. 64). Furthermore, Sars stated that the genital segment is perfectly symmetrical, but in the specimens from the Pacific (Fig. 47) and Georges Bank (Fig. 63) and in *tropica,* the left spine is larger than the right. We believe that the size and detail of these spines is variable and may be of little diagnostic value. Table 2 gives the total length, cephalothorax–abdomen ratio, and abdominal segment ratios of the specimen from Georges Bank, Pacific specimens, and Sewell's variety *tropica.*

The structure of the female fifth feet presents some variation among specimens from the Pacific and Georges Bank, Sewell's *tropica,* and Sars' description. Sewell stated that the fifth feet of *tropica* were unlike *norvegica* in that there are two rather than three "spines" on the outer margin of the distal segment, but Sars (1903) mentioned that this margin may have two or three small "denticles." Of our two Pacific specimens, one has two spinous processes on each foot (Fig. 54), and the other has two on one foot and three on the other (Fig. 55). The Georges Bank specimen has two outer spinous processes on each foot. It appears that this is a variable characteristic. In *tropica* the two terminal fingers of the fifth feet are equal, but in all others examined or described the length of the outer is about twice that of the inner finger.

Sars stated that the points on the corners of the fifth thoracic segment diverge in dorsal view, but in all other specimens and descriptions examined by us these points point straight caudad.

The male from the Pacific (Figs. 56–62) agrees closely with the Georges Bank specimen and with the description given by Sars. The total length of our specimen is 2.68 mm. and that of the Atlantic specimen is 3.23 mm.

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Swimming Performance of Juvenile Sockeye Salmon in Salt and Fresh Water

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ABSTRACT

An experiment was conducted to explore the hypothesis that the swimming performance of salmonoids in sea water is higher than that of similar fish in fresh water. Young sockeye salmon *(Oncorhynchus nerka)* swam longer in salt water. Duration of swimming increased with size of fish.

INTRODUCTION

Most information on salmonoid swimming performance comes from observations in fresh water relating to fish passage problems. Marine swimming performance studies have not received the same attention. Performance capacities in sea water are of interest as some estuarine hydraulic structures and impoundments may form sharp transitions between the marine and fresh-water environments, requiring migrating salmonoids to negotiate varying flows of saline or fresh water. Information on the relative swimming abilities in these different media would assist in interpreting the effects of such structures upon migrants. An indication that salmonoid swimming performances in sea water are different from performances in fresh water is suggested by the results of muscular fatigue experiments in which marine and fresh-water salmonoids were similarly exercised but the marine fish often did not recover.

In experiments assessing the effects of capture and handling upon salmon, Parker and Black (1959) caught marine chinook salmon (*Oncorhynchus tshawytscha*) and exercised them at sea on troll lines. They reported high mortalities following severe sustained 15-minute exercise. These studies were extended the following year to include marine coho salmon (*O. kisutch*) which were caught and similarly exercised at sea on troll lines (Parker *et al.*, 1959). Again mortalities followed as in the chinook experiments. However, when fresh-water-captured coho were subjected to the same exercise on troll lines in fresh water, no mortalities resulted.

In another muscular fatigue study Black (1957c) noted deaths occurring in 2-year-old hatchery reared sockeye salmon (*O. nerka*) which had been severely exercised for 15-minute periods in troughs of sea water. These fish had been exposed to salt water for 1½ years. Again, results contrasted with the results of similar controlled experiments in fresh water of Kamloops trout (*Salmo gairdneri*) (Black, 1955, 1957a) and lake trout (*Salvelinus namaycush*) (1957b) in which no mortalities were caused by exercise.

The relationship between extreme performance, or exercise, and death in fish has been reviewed by Black (1958). This mortality is generally attributed to a large increase in blood lactic acid released by the rapid breakdown of muscle glycogen, an energy reserve for severe muscular effort.

In the experiments cited, death following the severe exercise was correlated with significantly higher levels of lactic acid. These higher levels of lactate and the mortalities which seemed associated with the fish in a marine environment may indicate that in sea water the actual amplitude of muscular activity is greater for a given exercise period — that the salmonoid in sea water makes a greater effort than its counterpart in fresh water.

The purpose of the experiment described in this report was to examine the hypothesis that salmonoid swimming performance is higher in sea water than in fresh water by comparing, under controlled conditions, the duration of peak or "burst" swimming performances of young salmon in both media.

MATERIALS AND METHODS

The experiment was conducted at the Fish Behavior Laboratory of the Seattle Biological

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Laboratory, Bureau of Commercial Fisheries, Seattle, Washington. The available fish were 1-year-old sockeye salmon (*Oncorhynchus nerka*) from the Federal Hatchery at Winthrop, Washington. Their average weight was 7 grams.

Apparatus

A swimming channel was formed by connecting two water-tight boxes with a 48- by 4- by 3-inch trough which was screened at each end (Figure 1). A continuous stream was circulated through the channel by pumping salt or fresh water from one box to the other. A second pump accelerated the water velocity in the channel so that high performances, which were brief but conveniently measurable, were forced from the fish. Preliminary trials indicated that a velocity of 2 feet per second, measured with a current meter, required the fish to swim hard to maintain a positive position in the stream. This water velocity was used in the tests.

The fish were stimulated to swim against the flow by a small electric current between two electrodes placed in the water at the lower end of the trough. The applied voltage was low so that the current was just sufficient to cause avoidance. If a fish was held between the electrodes it appeared unaffected even after several minutes. To allow for differences in conductivity between salt and fresh water the voltages were regulated with a variable transformer. At the best evident response levels, the voltages were measured with a vacuum tube voltmeter. Ten volts across 3-inch electrode spacing gave the best stimulus in fresh water and 1.5 volts in salt water.

The temperature of the recirculating water was precisely held at the fish's environmental level by regulating coils which were immersed in the boxes.

The sea water used in the tests and for acclimation and holding was transported from Puget Sound and stored at the Seattle Laboratory. The fresh water was from the domestic supply.

Design

The general plan was to acclimatize 150 fish to salt water for 1 week, individually measure their swimming performances in the test channel, and compare them with a similar control group of 150 held in fresh water. The fish were acclimated in outdoor covered circular steel tanks 4 feet in diameter. Two hundred fish were placed in each tank to assure an adequate sample. Mortalities were replaced and at the time of testing the fish had been exposed to salt water for 1 week. Water was maintained in a closed system and aerated by recirculating pumps. The temperature was not regulated, but during this period the water temperature varied only be-

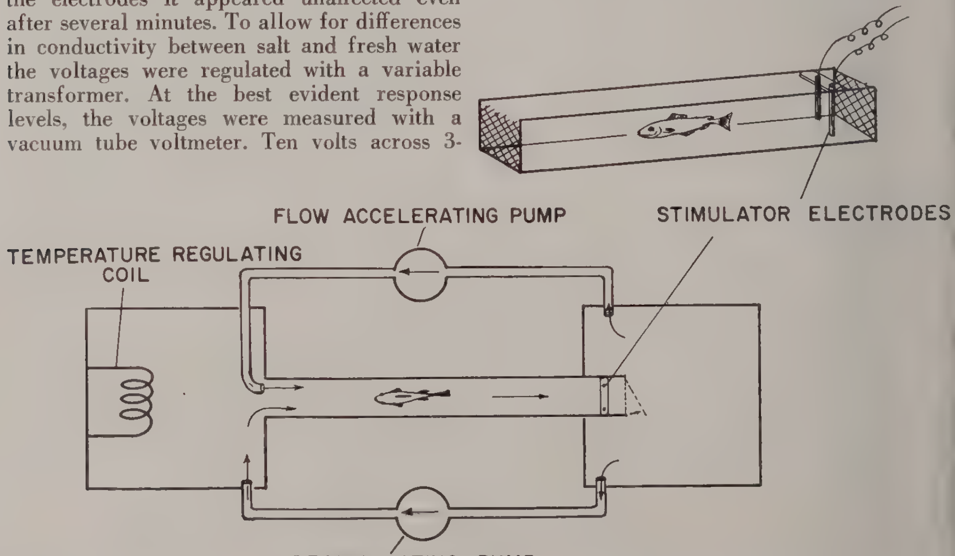

Figure 1.—Diagram of an exercise channel used to compare the swimming performances of yearling sockeye salmon in salt and fresh water.

tween 9° C. and 11° C. The fish were not fed during the experiment since individual variations in food consumption might have influenced performance capacities apart from the experimental variables. Tests were planned to cover a 2-day period so that each group of salt- and fresh-water fish was tested both morning and afternoon as follows:

Time	Day 1	Day 2
Morning	75 fish (fresh-water)	75 fish (salt-water)
Afternoon	75 fish (salt-water)	75 fish (fresh-water)

Procedure

The temperature of the test water was adjusted to the level of the outdoor acclimation tanks, and the velocity pattern was established in the channel. The electrodes were energized and a fish introduced into the trough to head into the stream flow.

When each fish could no longer hold its position away from the electrodes the swimming time was recorded and it was removed and weighed to the nearest gram. In this way swimming performance of fish of the same size could be compared in the different media.

RESULTS

The total mean swimming times of the two groups are compared in Table 1. The salt-water fish swam 43 percent longer in the test channel. However, the mortalities which occurred during acclimation removed mostly smaller fish from the salt-water group, so that the average weight of this group was 25 percent greater than the fresh-water average. This probably contributed to the overall increased salt-water performance, since it could be expected that larger fish generally would have correspondingly larger capacities to work against a constant water current.

DISCUSSION AND CONCLUSIONS

By recording individual weights and performances, the effect of fish size was evaluated in this test. This is illustrated in Figure 2, in which swimming time in the channel is plotted against fish weight. Each point represents the average swimming time of all fish of that particular weight in each test medium. Regression lines were calculated from these points.

A proportional size-performance relationship shows in each test group. The correlation appears closer with the salt-water ac-

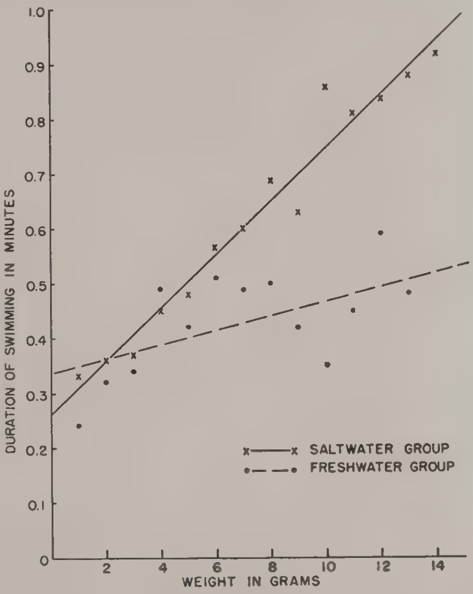

FIGURE 2.—The swimming performance and size relationship of two groups of exercised yearling sockeye salmon. One group was acclimated and exercised in salt water. The second group was exercised in fresh water.

TABLE 1.—*Summary of swimming performances of 1-year-old sockeye salmon in fresh water and salt water*

Test medium and time	Number of fish	Total weight (grams)	Average weight per fish (grams)	Total time of group (minutes)	Mean time (minutes)
Fresh water					
Morning	75	436	5.8	34.44	0.46
Afternoon	75	519	6.9	31.58	0.42
Total group	150	955	6.3	66.02	0.44
Salt water					
Morning	75	526	7.0	44.56	0.59
Afternoon	75	666	8.9	49.21	0.66
Total group	150	1,192	7.9	93.77	0.63

climated fish. Brett, Hollands, and Alderdice (1958) reported a similar effect of size on swimming performance with juvenile sockeye and coho salmon.

The fish swam for longer periods in salt water. The increased performance agrees with observations of Black (1957c) who noted that exercised sea-water acclimated yearling sockeye were more active than similar fish in fresh water.

Since these results were from tests with acclimated juvenile fish, only speculative extrapolations can be extended to salmonoids in their marine environment. However, no disagreement seems evident if the exercise experiments of Black (1957c) and Parker and Black (1959) are reconsidered with these results. The indications are that a salmonoid probably performs at a higher level in salt water than in fresh water.

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FISHERIES RESEARCH

F2.

Observations on the Stomach Contents of the Silver Hake

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SHORT PAPERS AND NOTES

Observations on the Stomach Contents of the Silver Hake

The available published reports on the food habits of silver hake, *Merluccius bilinearis* (Mitchill), place great emphasis on the importance of fish as a food item of this species (Goode, 1884; Nichols and Breder, 1927; Bigelow and Schroeder, 1953). Invertebrates, if mentioned at all, are considered secondary as food items. The purpose of this note is to present the results of some observations of the contents of silver hake stomachs collected in the waters off the northeast coast of the United States. These data were collected incidentally to other studies and are not intended to serve as a definitive report on the food habits of the species. Because there is a scarcity of such reports, however, we wish to place our observations on record.

The fish were caught by otter trawl and the fork length of each was measured. The stomachs were removed, the contents identified, and the frequency of occurrence of food items was recorded by counting the number of stomachs in which that food item was found. A stomach which contained, for example, both fish and Crustacea was counted twice, once for fish and once for Crustacea. The method of recording stomach contents by frequency of occurrence does not take into account the sizes of the food items involved and thus equates, for example, one fish and one shrimp. This method affords only a rough indication of the food habits of the animal. A total of 348 silver hake stomachs was examined, of which only 153 (44 percent) contained food. The stomach-analysis data are listed in Table 1.

Sample 1 was collected in August 1954 northeast of Provincetown, Massachusetts (lat. 42° 08′ N., long. 70° 05′ W.), in 26 to 36 fathoms of water. The sample consisted of 111 fish with a range of 23 to 62 centimeters in length. Twenty of these fish had food in their stomachs; all were females and ranged from 32 to 62 centimeters in length. Silver hake, herring, and unidentifiable fish remains were found in 19 of the stomachs. Three stomachs also contained euphausiid shrimps or squid.

Sample 2 was collected in September 1955 at a depth of 60 to 117 fathoms in Georges Basin (lat. 42° 52′ N., long. 66° 53′ W.). Of a total of 116 fish ranging in length from 16 to 47 centimeters, 65 fish, all less than 36 centimeters long, had food in their stomachs. Euphausiid shrimps were the most common item and occurred in 58 stomachs. The only

TABLE 1.—*Stomach contents of fish in four samples of silver hake—expressed as number of stomachs in which item occurred*

Item	Sample			
	1 August 1954 Provincetown	2 September 1955 Georges Basin	3 October 1956 Point Judith	4 October 1958 Montauk Point
Fork lengths of fish in sample (centimeters)	23.5-62.1	16.0-47.1	18.9-38.1	19.5-46.5
Number of stomachs examined	111	116	80	41
Number with food	20	65	37	31
Percentage containing food	18.0	56.0	46.2	75.6
Food items				
Molluscs	2	—	—	—
Loligo sp.	2	—	—	—
Crustaceans	1	58	25	16
Euphausiids	1	58	25	—
Decapods	—	—	—	16
Fish	19	7	15	15
Clupea harengus	3	—	—	—
Merluccius bilinearis	13	—	—	4
Stenotomus versicolor	—	—	3	—
Unidentifiable fish remains	3	7[1]	12	11

[1] Believed to be *M. bilinearis.*

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LAGENIDIUM CALLINECTES COUCH IN BARNACLE OVA

By T. W. Johnson, Jr. and Rupert R. Bonner, Jr.

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LAGENIDIUM CALLINECTES COUCH IN BARNACLE OVA

BY T. W. JOHNSON, JR.[1] AND RUPERT R. BONNER, JR.[2]

In 1942, Couch described *Lagenidium callinectes* from ova of the blue crab, *Callinectes sapidus* Rathbun. Subsequently, Rogers-Talbert (1948) published an account of the fungus in "sponges" (egg masses) from blue crab in the Chesapeake Bay. She gave particular attention to ecological factors. Through the courtesy of Dr. John D. Costlow of the Duke University Marine Laboratory, we were initially provided with infected lamellae of the barnacle *Chelonibia patula* Ranzani. The fungus in these egg masses, and in ones subsequently collected, was examined in various developmental stages, and identified as *L. callinectes.* This paper reports our observations.

Chelonibia patula is a large, white or gray-white barnacle that occurs commonly on the carapace of *Callinectes sapidus* (particularly the old females), and on *Limulus polyphemus* L. (King or Horseshoe crab), among other marine animals. *Chelonibia* lamellae are large, usually paired, and white; as the embryos develop, the eggs undergo color change.

Lamellae were dissected from the animals and placed in raw (as opposed to "aged") sea water. For examination, the material was mounted on ordinary slides or in depression slides. Cross-inoculation and infection tests were carried out as follows: 25 ml of raw sea water were put in each of 10 Petri plates. A small portion of blue crab "sponge" (about 25 ova) was put in each dish, and one infected barnacle lamella added. These cultures were incubated for 48 hours at 25°C, the barnacle eggs removed, placed in separate dishes, and all plates then re-incubated for one week. On the ninth day the crab eggs were examined for infection. Three control plates, consisting only of the crab ova in sea water, were also incubated for the 9-day period. Ova for controls were taken from the same "sponge" used in the cross-inoculation plates.

Characteristics of *Lagenidium callinectes* in barnacle ova differ in some respects from those of the same species as recorded by Couch (1942). The most obvious difference, perhaps, is the preponderance of extramatrical hyphae in the fungus from barnacles. According to Couch, *L. callinectes* mycelium develops entirely within the ovum membrane of the blue crab, but sporulates extramatrically by producing sporangial discharge tubes. The extramatrical hyphae of the fungus in *Chelonibia* are 8–14 μ in diameter, and usually profusely branched; the longest hypha measured was 1030 μ. Internally, the extramatrical hyphae are either reticulately vacuolate or have very diffuse cytoplasm containing numerous refractive oil globules. The emergent hyphae are without septa, but the intramatrical ones are sparingly septate. Commonly, the emergent hyphal apices are bulbous; as far as is known, these expansions do not develop into sporangia. Intercalary globose swellings also develop in the extramatrical filaments. Hyphae within the ovum, however, are very similar to those described by Couch: stout, sparingly septate, irregular, and filling the ovum.

Sporangium and discharge vesicle formation in the fungus from *Chelonibia* are similar, but not identical, to the stages described and illustrated by Couch (1942, pl. 19, figs. 12–14) for the crab-egg fungus. Two features are dissimilar. The first of these is development of the sporangial vesicle at the apex of the long, emergent hyphae. The second difference is in the nature of the vesicle in its early formation. As the vesicle enlarges (at the tip of the sporangial discharge tube), its wall does not seem to be gelatinous. Rather, it is consistent with, and of the same thickness as, the hyphal wall. The vesicle, therefore, is merely an expansion of the discharge tube apex, and is not secreted internally from the tube.

Sporangia are produced through intramatrical hyphal segmentation. Consequently, some of the emergent hyphae (those ultimately producing a vesicle) are the sporangial discharge tubes. In *Lagenidium callinectes* from blue crabs, these discharge tubes are short; in the same species from *Chelonibia* ova, the tubes are very long. Figures 10 and 11 accompanying Couch's paper (1942, pl. 19), applying to the fungus in crab eggs, also illustrate adequately the features of discharge tube penetration through the barnacle ovum membrane. However, the discharge tube base, as it enters into and emerges from the membrane (barnacle), is not markedly thickened as Couch figures it (1942, pl. 19, figs. 12, 13) for *L. callinectes* in blue crab.

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Spore emergence in the *Lagenidium* from *Chelonibia* ova is precisely like that described for *L. callinectes.* The planonts are cleaved within the vesicle and escape through a lateral or terminal break in the persisting vesicular wall. Planonts are the same size as those described by Couch.

As in the *Lagenidium* from blue crab ova, the fungus in barnacles produces resting cells (18–36 μ in diameter), but these are apparently uncommon. Of the few examined, all but one were intercalary in the hyphae; the exception was terminal. Two such resting "spores" were observed during germination. The oil deposits migrate centrally in the resting cell, and gradually disappear. As the oil bodies disintegrate (?) the resting cell wall becomes thin, and the entire body enlarges slightly. At one point on the wall, an evagination develops which elongates to become a hypha with the characteristics of the intramatrical filaments. Because the hyphae from the two germinating resting cells became intermingled with other intramatrical filaments, it was impossible to follow further developmental stages.

Seven of the ten cross-inoculation and infection cultures were positive; that is, the *Callinectes* ova were infected by the fungus growing in *Chelonibia* lamellae. The three negative cultures probably resulted from failure of the fungus in barnacle eggs to sporulate, hence inoculation could not occur. None of the blue crab ova in the controls was infected. Only one sporangium that developed in experimentally-infected *Callinectes* ova produced a discharge tube. This tube was short and thick-walled at the entrance and exit through the ovum membrane, just as Couch (1942) figured it for the fungus in blue crab. Sporulation had occurred, since the discharge tube apex was expanded into an empty, partially deliquesced vesicle. Other than this single discharge tube, there were no extramatrical hyphae coming from the *Callinectes* ova, although the eggs were filled with mycelium. The successful cross-infection confirms, we believe, the morphological evidence that the fungus in barnacle lamellae is the same species as that in the *Callinectes* "sponges."

Both Couch (1942) and Sparrow (1939) recognized that the generic limits of *Lagenidium* could well be revised. Including, for example, *L. chthamalophilum* (Johnson, 1958) with its preformed, evanescent vesicle, markedly changes certain concepts with respect to the genus. *Lagenidium callinectes* from *Chelonibia* has one characteristic, certainly, that is not a part of the genus as it is now understood. This feature is the profuse extramatrical hyphal system. In assimilative growth, at least, *L. callinectes* approaches certain myceloid members of the Pythiaceae and Peronosporales. There is increasing evidence, we believe, that if the generic limits of *Lagenidium* are not extended, the coarse mycelial forms such as *L. callinectes* and *L. chthamalophilum* cannot in all likelihood be retained in the genus.

One point in connection with *Lagenidium callinectes* should be emphasized. In keys to members of *Lagenidium* there is at least an indication that most species are host specific. *Lagenidium callinectes*, certainly, is not. However it is not surprising to find the fungus from blue crab ova invading the eggs of the barnacle, or vice versa. The close proximity of the two suscepts is adequate to account for the cross-transfer.

SUMMARY

Lagenidium callinectes Couch is reported from lamellae of *Chelonibia patula*, a barnacle developing on the carapace of *Callinectes sapidus.* Extramatrical hyphae are very abundant in the fungus as it occurs in *Chelonibia*, in contrast to the exclusively intramatrical hyphae of the same species in *Callinectes* ova. The fungus can infect blue crab eggs, under laboratory conditions, in nonsterile, raw sea water.

ACKNOWLEDGMENTS

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An Illuminator for Observing and Photographing Precipitin Reactions in Agar

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and GEORGE P. WILSON**

Abstract

An illuminator employing a modified darkfield principle is described which has been found to be especially suited for observing and photographing the agar plate and micro-slide techniques of double diffusion precipitin analysis.

IN 1949 Ouchterlony[1] described a new technique to demonstrate heterogeneity in antigenic solutions. This technique, termed the agar plate method of double diffusion precipitin analysis or simply agar diffusion, employs the specific interactions of antigens with their respective antibodies as they diffuse towards each other through a semi-solid medium contained in a petri plate. When they meet in optimal proportions with each other, a line of precipitate is formed. Differences in initial concentration and optimal proportion zones of the individual antigens and their respective antibodies are responsible for the formation of separate lines of precipitate.

Within the past few years the agar diffusion technique has been used in several phases of immunology[2,3]. One of the problems inherent in its application is the need for an adequate means of observing and recording the results. Free-hand and camera lucida drawings have been used to record the precipitation reactions. These methods, however, are difficult to accomplish accurately and are time consuming when complex systems are involved.

Photographic methods, on the other hand, have given superior results in the ease and accuracy of recording precipitation lines. A simple method of photographing the lines is to make a contact print. This can be accomplished in the darkroom by placing a sheet of photographic paper or a lantern slide beneath the plate and exposing it with a direct overhead light. Two limiting factors in this method are the insufficient contrast to record the fainter lines and the appearance of wrinkles in the glass and agar as lines in the print. Another photographic method is the use of a camera in conjunction with oblique illumination of the agar plate. Lawson[4] has described the use of such a combination.

This paper describes an apparatus we developed and designed to observe and photograph the lines of precipitate as they are seen in the agar plate method of Ouchterlony[1] and the microslide modification of Grasset et al[5]. This apparatus utilizes the combination of a

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camera and darkfield illumination of the agar plate and was developed to overcome the inadequacies of the techniques mentioned above. It also has the advantage of being portable and relatively inexpensive to construct. This apparatus is similar in principle to the one described by Schutz[6], since it provides modified darkfield illumination. However, the source of illumination is incandescent rather than fluorescent and, as a consequence, our apparatus is smaller and simpler to construct.

Description of the Apparatus

The apparatus consists of a wooden base supporting a stainless steel and brass camera mount with a stainless steel illuminator (Figure 1). The end of the base opposite the illuminator is used for micro-film photography.

The light housing of the illuminator (Figure 2) is a cylinder five inches in

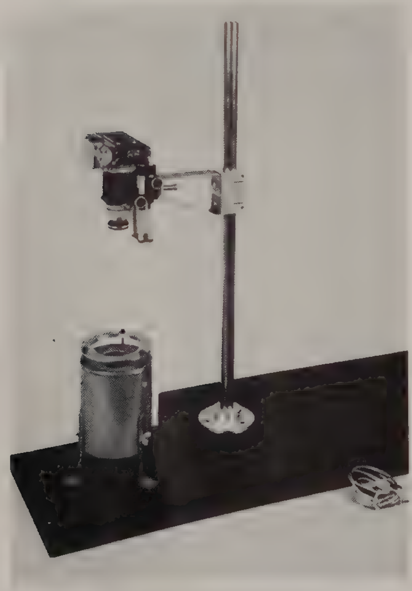

Figure 1. Camera and illuminator.

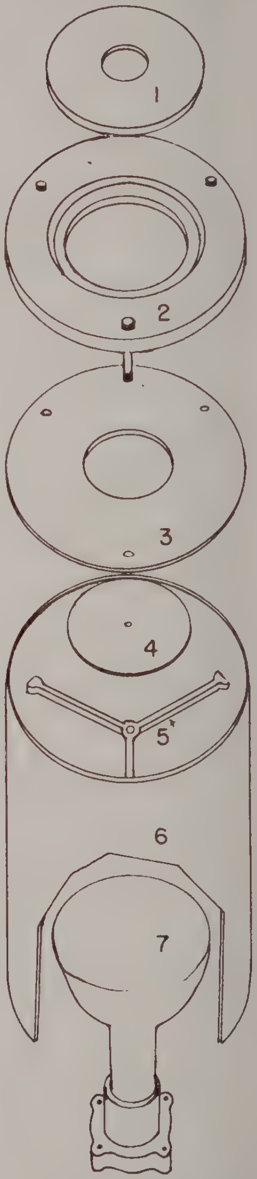

Figure 2. Exploded view of the illuminator. (1 Adapter plate for micro-slides. (2) Plate carrier. (3) End-plate. (4) Baffle. (5) Baffle moun (6) Light housing. (7) 75W reflector bulb an socket.

diameter and seven inches long, with a plate welded on the upper end. It is lined with aluminum foil for proper cooling and light reflection. A hole 60 mm. in diameter is machined in the exact center of the end-plate. A baffle 65 mm in diameter, attached to a Y-shaped mount by an adjustable screw, is centered beneath the hole. The upper surface of this baffle is painted dull black. The plate carrier is mounted on the light housing with three adjustable machine screws. The entire light housing assembly, including the plate carrier and baffle, is centered over a 75W reflector bulb and attached to the base with three adjustable stainless steel legs.

A functional prototype of the light housing assembly was made from a tin can of approximately the same size, with the rest of the parts fashioned from sheet aluminum. This prototype was in use for two years and gave very good results.

An uncharged plate is placed on the carrier to adjust the apparatus for optimal illumination. The baffle, light housing, and plate carrier are then manipulated to obtain the smallest circle of light on the surface of the agar. The adjustments are best achieved in a darkened room.

A single lens reflex 35 mm camera with a 105 mm lens mounted on extension bellows is used for photographing the reactions in petri plates. A 50 mm lens is mounted on the extension bellows when photographing the reactions on micro-slides. Various types of black-and-white and color films have been used successfully in photographing the lines of precipitation.

Results

Through the use of this apparatus we have been able to conveniently observe and keep permanent photographic records of several thousand plates set up during the past three years (Figure 3). The photographs are free of artifacts due to wrinkles and flaws in the glass plates

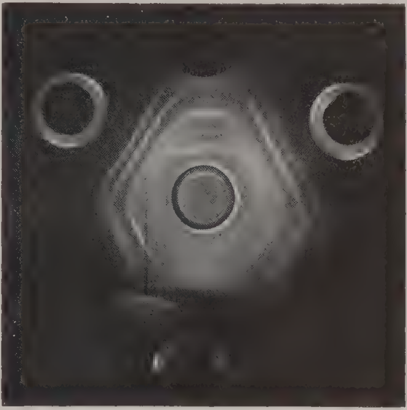

Figure 3. Photograph of an agar plate, using the illuminator described. The center well contains rabbit anti-salmon serum and the peripheral wells contain salmon sera. The three unexposed areas are due to the presence of hemoglobin in the sera.

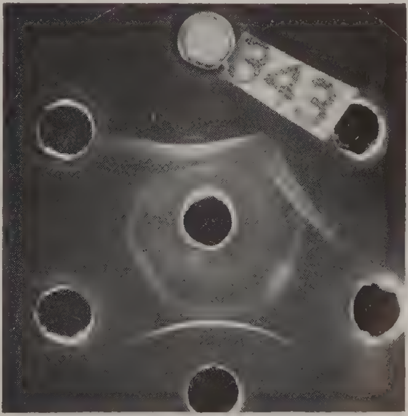

Figure 4. Photograph of micro-slide technique, using the illuminator plus an adapter plate. The center well contains rabbit anti-salmon serum and the peripheral wells contain salmon sera.

and agar. Such artifacts were frequently encountered in records made by contact printing.

When recording results obtained from the micro-slide technique, it is necessary to place an adapter in the plate carrier and enlarge the action area (Figure 4). A contact print in this case would be too small and require viewing with a hand lens in order to see the detail.

An advantage of using a camera to record the lines of precipitate is the ease with which enlargements and duplicates can be made. With the contact print method one must know beforehand how many prints are required, since much of the detail is lost in trying to reduplicate from a print.

Summary

An illuminator which utilizes a modified darkfield principle is described. This apparatus is especially suited for the observation and photographic recording of lines of precipitation appearing in either the petri plate method, or the micro-slide modification, of the double diffusion precipitation analysis.

ACKNOWLEDGEMENTS

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ilization of Organic Carbon a Marine Crustacean: nalysis with Carbon-14

Abstract. An isotope-dilution techque using carbon-14 was employed to ermine quantitatively the carbon budget a filter-feeding crustacean. The amount carbon ingested ranged between 0.044 d 0.139 mg. Incorporation of carbon ried between 11.3 and 73.6 percent per y per organism, with an average of 32.5 rcent for the animals tested. Values for ygen consumption are given as they ate to carbon intake and utilization.

Energy and feeding interrelationships ve been experimentally determined r some zooplankters. For example, chman (*1*) determined a calorimetric dget for the fresh water crustacean *aphnia pulex*, and Marshall and Orr) used radioactive carbon to deterine the filtering rates and the percent food digested by the marine copepod, *alanus finmarchicus*. The latter authors ade no attempt at a quantitative meas- e of carbon in their experiments. This port presents a method which utilizes isotope-dilution technique for quan- ative measurements of the utilization nd egestion of particulate organic carbon by a planktonic filter-feeding marine crustacean, *Euphausia pacifica*.

The experimental animals *(E. pacifica)* were collected in net hauls (at a depth of about 250 m) off the coast of La Jolla and were brought back at 10°C to the laboratory within a few hours.

A period of 24 hours was usually allowed for the unfed captive animals to void particulate matter from the gut. Eight-day-old, 50-ml, bacteria-free cultures of a green algal flagellate, *Dunaliella primolecta*, grown in a sea water medium (*3*), were labeled with C^{14} (10 μc of $NaHC^{14}O_3$) for 3 to 4 days and were then supplied as food. The amount of carbon in the food offered to the animals in the laboratory ranged between 0.117 and 0.313 mg.

On the day of an experiment the algae were collected by centrifugation, washed free of soluble C^{14}, and suspended in sea water previously filtered through Millipore membranes (0.45 μ porosity). Total organic carbon and C^{14} measurements were determined for aliquots of the algal culture. This information provided the proportion of total carbon to C^{14} in the algae. The culture was suitably diluted to give approximately 0.1 to 0.3 mg of algal carbon in a vessel (about 1 to 3 × 10^5 cells per milliliter). Each vessel was then supplied with an adult euphausiid (dry weight 3 to 5 mg). When euphausiids are put into a heavy suspension of algae, that is, enough cells to tint the sea water green, they quickly filter out enough algae to completely fill the intestine, digestive gland, and crop. Control bottles without animals were included to ascertain the amount of algal respiration. Bottles were usually of 65-ml capacity and contained 40 ml of fluid, but occasionally larger bottles were used. At the start of the experiment an aliquot of the sea water containing the radioactive algae was removed to determine the quantity of organic carbon available to the animals. The method of Kay (*4*) was used for measurement of organic carbon. Another aliquot of algae was retained on a Millipore filter (pore size, 0.45 μ) and analyzed for C^{14}.

The experimental bottles and the contents were kept in the dark at 10°C for 24 hours. Then the animals were removed, washed in filtered sea water, and dissected to remove both their

Table 1. Fractionation of carbon by radioactivity. In this experiment, the carbon for each fraction was calculated by use of the ratio

$$\frac{27.9 \times 10^3 \text{ cpm}}{0.174 \text{ mg C}} = \frac{\text{Observed cpm}}{x}$$

where cpm is counts per minute.

Material analyzed	10^3 cpm	Total C (mg)
	Time: 0 hours	
40 ml Dunaliella culture	27.9	0.174
	Time: 24 hours	
40 ml Dunaliella culture	5.07	0.032
Ingested (by difference)		0.142
Egested in fecal pellets	1.27	0.008
Eviscerated euphausiid	16.7	0.104
Catabolized (by difference)		0.030

intestinal tracts and digestive glands. Fecal pellets were removed from the water with a pipette and washed gently. Finally, another aliquot of the algae was taken out and filtered for C^{14} determination.

After drying, each eviscerated euphausiid was weighed, combusted to carbon dioxide, and assayed for total carbon (*4*). The mean of 16 carbon determinations is 34.6 percent on a dry weight basis (range 25.4 to 39.0 percent). The CO_2 thus produced was recovered as $BaCO_3$ and counted for C^{14} radiation in a windowless proportional counter (Nuclear Measurements Corporation). The amount of C^{14} activity in the barium carbonate was corrected against a self-absorption curve. The radiation emitted by the radioactive algae was also counted. No self-absorption correction was made for filtered algae because of the extremely low weight of the sample and the lack of measurable absorption of the C^{14} radiation (*5*).

Knowing the C^{14}/total C ratio of an algal sample permits the calculation of the total carbon contributed by the algae, as shown in Table 1. The constancy of the ratio C^{14}/total C was tested. It appears that there usually is a change, due to respiratory processes, of −4 to −5 percent in this ratio over the experimental period. Table 1 presents the results of a typical experiment.

Table 2 gives the carbon balances calculated from the C^{14}/total C ratios found for eight animals at different phytoplankton densities. Also shown are the calculated efficiencies with which these animals were able to accumulate carbon in their tissues through digestive processes.

Respired CO_2 was not determined directly but was estimated by difference. An indirect gasometric method was used also to calculate the magnitude of total respiratory carbon for comparison with the C^{14} method. Oxygen consumption was found to be linear over several hours at 10°C by tests with the water analyzer devised by Scholander *et al.* (*6*). Q_{O_2} values were based upon eight analyses of individual animals, and showed a range of 0.85 to 1.52 ml/gm per hour, from which the mean of 1.14 was derived. On the assumption that the respiratory quotient was 1.0, CO_2 evolution was calculated from the average oxygen consumption, and was found to have a reasonably close correspondence in some cases with data collected by the C^{14} method (animals Nos. 1 to 4, Table 2).

Some animals (Table 2) showed a larger catabolic carbon fraction than could be accounted for by respiratory processes alone. It is probable that catabolic carbon compounds other than CO_2 are excreted by the animals.

From Table 2 it is also seen that large variations may exist in the efficiency of these zooplankters to incorporate ingested carbon. In the animals tested, this ranged between 11.3 and 73.6 percent. However, the fate of the incorporated carbon was not ascertained. These data may reflect deposition of storage products or actu growth.

The effect of varying temperatur on oxygen utilization was tested gasometrically. The euphausiids were foun to have a Q_{10} of approximately 2 between 5° and 12°C. This would impl that when these animals cross th thermocline into warmer water the basal carbon needs increase. Howeve except those by Fox *et al.* (*7*), fe published data exist on the amount o particulate carbon available for zooplankters in the sea.

Application of the method presente in this paper to other organisms, wit proper attention to the experimenta variables cited here, may permit a direct measurement of the carbon flo through biological systems in aquati environments. Future investigation call for studies of relative nutritiona states and comparative proportions o stored reserves in experimental animal (*8*).

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Table 2. Carbon budget of *Euphausia pacifica*. All weights are given in milligrams.

No.	Dry wt. of animal	Wt. C in eviscerated animal	% C in animal	Wt. algal C offered to animal	Wt. C ingested by animal	Wt. C incorporated	% C incorporated	Wt. C of gut and gland	Wt. C egested	Wt. catabolic C, including CO_2	Wt. C respired (calculated from RQ = 1)
1	4.6	1.66	36.6	0.174	0.139	0.102	73.6	< 0.001*	0.009	0.029	0.033
2	3.7	1.22	33.0	0.156	0.057	0.018	31.6	0.005	0.006	0.028	0.026
3	3.0	1.01	33.6	0.156	0.056	0.021	37.8	0.003	0.007	0.025	0.021
4	3.9	1.49	38.2	0.117	0.044	0.005	11.3	< 0.001*	< 0.001*	0.039	0.028
5	4.1	1.60	39.0	0.276	0.097	0.015	15.5	0.003	0.001	0.079	0.029
6	4.6	1.74	37.8	0.313	0.113	0.020	17.8	0.002	0.002	0.065	0.033
7	3.4	1.27	37.4	0.313	0.147	0.062	42.2	0.011	0.002	0.073	0.024
8	5.1	1.62	31.8	0.313	0.101	0.029	29.7	0.006	0.001	0.065	0.035

* Weight not determinable by the method used.

USE OF CHEMICAL BARRIERS TO PROTECT SHELLFISH BEDS FROM PREDATORS

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The necessity of controlling enemies of mollusks grown for human consumption was obvious even in the days of the Romans. Later on, especially since the middle of the last century when cultivation of oysters acquired significant importance, a desire to diminish the losses due to predation was common among cultivators of America, Europe and Japan. Regardless of limited success in some instances predators continued to present an important problem and, sometimes, won the battle. For example, recently a prevalence of drills in Long Island Sound compelled the oyster industry virtually to give up the entire area of Milford Bay, where only a decade or so ago highly productive seed oyster beds existed. Almost total extermination of the extremely heavy oyster set of 1958 in Long Island Sound by starfish is another example. These two cases are sufficient to illustrate that, until now, a good general method of controlling these predators was not available. **In this report we offer the description of a new, cheap, simple, but effective chemical method of the kind for which shellfish industries have been hoping for the last two thousand years.**

Our plan to use chemicals in building barriers against shellfish predators does not mean, of course, that we fail to realize the serious danger that may be created by their indiscriminate use. On the contrary, during our screening of more than two thousand chemicals and early experiments on development of barriers we saw how extremely toxic many of these substances were to aquatic forms. Nevertheless, it would be irrational to condemn outright the use of chemicals in aquaculture. Instead, we should critically evaluate the desirability of their usage by comparing their positive and negative values. This can be achieved only by well-designed studies. It may be emphasized now, however, that compounds that we selected for use in chemical barriers are virtually insoluble in sea water. Therefore, when used in relatively small quantities, these chemicals are not dangerous pollutants.

The method and its ramifications and modifications described here are designed to control boring gastropods, such as oyster drills and **Polinices**, starfish, crabs and other enemies of commercial mollusks, primarily by preventing their invasion of shellfish grounds. The basic idea of the method is comparatively old, having been advocated and developed by the senior author since 1946. It is founded on the principle of surrounding the beds with "barriers" or "belts" containing chemicals which either stop, repel or kill undesirable forms.

In the initial experiments carried on in the middle 1940's, chemicals were incorporated into such materials as plaster of Paris, concrete, common bricks, slag, gelatin, agar, ropes, etc., which could be placed directly on the bottom and affect the pests coming in contact with them. Later, we recalled the use of carbonized sand to sink oil floating on the surface of water, and thought that oil could be, therefore, used as a medium in which toxic substances could be incorporated and later deposited on the bottom. Presumably, such mixtures would remain active for long periods, continuing to repel or kill the enemies of such bivalves as oysters, clams, scallops and mussels.

Still more recently we began to use heavy oils, such as trichloroethylene, tetrachloroethylene, monochlorobenzene, orthodichlorobenzene, paradichlorobenzene, trichlorobenzene, tetrachlorobenzene and their mixtures. At first, these oils were considered merely because they are heavier than water and thus

easy to deposit and keep on the bottom. However, during the preliminary experiments we discovered that these oils, in themselves, are toxic to several shellfish enemies, including drills, starfish and crabs.

While experimenting with different carriers, we found that many of the heavy oils could be easily deposited on the bottom and kept there quite securely by mixing them with common dry sand. This solved one of the problems in the practical application of the method, especially that of stabilizing oil once it is placed on the bottom. We are experimenting further by testing relatively cheaper but lighter oils or mixtures of light and heavy oils, which may be sunk with sand, gravel or other carriers. These experiments will help us to determine which approach is most practical and economical.

As mentioned before, preliminary experiments with heavy oils showed that some of them, such as orthodichlorobenzene, are sufficient in themselves to repel, cause swelling or even kill drills. Subsequent observations indicated that other gastropods, including **Polinices, Busycon, Thais** and **Nassa,** were also affected by them. Thus, these oils in themselves appear to be sufficiently effective to act as chemical barriers to stop gastropods. Nevertheless, since in our screening studies we found several substances, other than heavy oils, which affect snails, the possibility of using them together with oils was also considered. One of the first substances tried was Sevin, 1-naphthyl-N-methylcarbamate, an insecticide manufactured by the Union Carbide and Chemical Company. Sevin was selected because it is relatively non-toxic to mammals and because we found that it immobolizes aquatic gastropods and causes them to swell so that their bodies helplessly protrude from shells. Thus, by incorporating Sevin in the oils, the efficiency of the barriers against gastropods was increased.

Sevin was also found to be highly toxic to crabs. It may be used in the oil barriers in combination with Lindane and other insecticides.

Another, and often the most destructive oyster enemy in some sections of this country, especially Long Island Sound, is the common starfish, **Asterias forbesi.** This pest sometimes invades oyster grounds in large numbers, causing extremely heavy losses. Even in the preliminary stages of our experiments we discovered that starfish can also be immobilized or their direction of movement changed by chemical barriers. This can be achieved by incorporating in the oils certain compounds which we found to affect starfish. One of these is 2-chloro-1-nitropropane.

Eventually, as a result of our experiments, several mixtures or formulas were developed, some of which can, simultaneously, stop the movements of boring gastropods, starfish and crabs. One of these is orthodichlorobenzene, a heavy liquid oil containing 2-chloro-1-nitropropane and Sevin, mixed with sand. In some formulas, for example, those containing paradichlorobenzene, a solid, the addition of wetting agents is desirable to prevent the formation of air bubbles when the mixture is placed in the water.

Among the many chemicals tested the following were chosen as being effective under certain conditions against the pests:

Drills and Other Gastropods

Dimethallyl sulfide
Phenyl allylsulfide
2, 3-Dibromo-1, 4-dichlorobutane
3, 4-Dichlorobenzyl chloride
Tetraethyl pyrophosphate
Sevin -1-naphthyl-N-methylcarbamate

Starfish

2-Nitro-2-ethyl-1, 3 propane diol dipropionate
5-amino-2, 5-diethyl-2-methyl-1, 3-dioxane
2-chloro-1-nitropropane
N^1, N^1-Dibutyl-2-methyl-1, 2-propane diamine
Tris (acetoxymethyl) dimethyl amino methane

Crabs

Sevin-1-naphthyl-N-methylcarbamate
Lindane - benzene hexachloride (gamma isomer)
Guthion - O, O-dimethyl-S (4-oxo-benzotriazino-3-methyl) phosphorodithioate
Parathion - O, O-diethyl-O-p-nitrophenyl thiophosphate
Disyston - O, O-diethyl, S-2 (ethylthio) ethyl phosphorodithioate

The above chemicals are not necessarily listed in order of their effectiveness. In addition to these, many other effective compounds were found. Not all of them have been tried as yet in chemical barriers.

The effectiveness of the barrier depends, naturally, upon many variables, including its width and the proportions of sand, oils and chemicals constituting

it. The species of the enemies to be stopped, perhaps even their size and age, general condition of the bottom, silting, velocity of currents, and the temperature and salinity of the surrounding water should also be considered. We may give, nevertheless, a single illustration of the potential effectiveness of barriers by mentioning one of our experiments in which a barrier composed of sand and orthodichlorobenzene and only eight inches wide remained effective from February 4, 1959 until the present [July, 1959], a period of about six months. During this time not a single drill managed to cross the barrier, although new groups of 10 drills were placed in the trough every two weeks. The temperature during this time varied approximately from 14.0° to 25.0°C. This barrier may remain active several months longer.

Practically no starfish managed to cross a barrier only three feet wide composed of sand, orthodichlorobenzene and 2-chloro-1-nitropropane or of a mixture of orthodichlorobenzene, trichlorobenzene and tetrachlorobenzene. Many barriers only a few inches wide stopped them for several days. In practice, to be certain of stopping all starfish, and to compensate for the fact that starfish may sometimes be carried by currents for some distance, the barrier should be considerably wider.

Since this paper is of a general character, we shall give only a few examples of the action of chemicals used in barriers. We may repeat that practically all heavy oils caused swelling of gastropods, including drills, **Polinices, Busycon, Thais** and **Nassa.** Sevin affected them in the same way. Gastropods with swollen bodies were unable to move and, under natural conditions, probably would be devoured soon by fish and other enemies. Some of them died after being in the proximity of the barriers for several days. However, if returned to pure sea water, they usually recovered within a few hours.

While in gastropods swelling of the bodies is one symptom of distress, in starfish, the first sign is usually a curling of the tips of the rays. Often, a starfish acquires an arched position, standing on the tips of its rays. In extreme cases, the starfish may roll into a ball. After a relatively short period of two or three days of contact with the barrier, the lower surface of the starfish begins to disintegrate. It usually starts at the tips of the rays and proceeds towards the central disc, but wounds may appear anywhere on the underside. Casting of the rays often follows.

Affected crabs first begin to show signs of distress by loss of equilibrium and later, convulsions. Toward the end they usually turn on their backs and die in this position.

Starfish placed on a barrier with their aboral surface down are often unable to turn over, and the delicate membrane covering that surface rapidly disintegrates. This observation led to another utilization of oil-treated sand, consisting of spreading it over oyster bottoms infested with starfish. Particles of sand carrying oil and, if necessary, other chemicals, drop on the upper surface of starfish and imbed in the membrane covering their bodies, quickly disintegrating them and eventually causing death. In principle, this method resembles that of using lime, which we developed and described over 20 years ago.

Our laboratory experiments have shown that spreading chemically-treated sand, gravel or other carriers over the oyster beds may serve other important purposes. For example, we found that if chemically-treated sand is spread over drill-infested bottoms, the majority of these gastropods soon die. The only survivors are those present, at the time of treatment, at the highest points of the oyster clusters where particles of treated sand do not stay. However, when these survivors, in search of food, try to cross low areas covered with treated sand, they become affected and also die.

The treated sand may also be used in the preparation of oyster bottoms for collection of set. In such instances, after the area is cleaned mechanically, i.e., by regular or suction dredges, the chemically-treated sand, gravel, etc., should be spread over it to kill the remaining drills and prevent re-infestation of the area from adjacent grounds. Several modifications of the two above-mentioned approaches readily suggest themselves.

Many aquatic invertebrates have pelagic larvae which can float over barriers and set on beds which have previously been cleaned of shellfish enemies. This is true of larvae of starfish, certain gastropods, worms and crabs. This circumstance would appear virtually nullifying the usefulness of chemical barriers because they, obviously, cannot prevent re-invasion of oyster beds with new generations of enemies

ving pelagic larvae. By using a variation of our thod, however, such re-invasions may be prevented. is preventative step should consist of spreading er cleaned shellfish beds a thin layer of treated sand, ntact with which will kill setting young gastropods, rfish and crabs.

Certain predacious gastropods, such as **Polinices,** e able to move under several inches of bottom soil. us, these forms may travel under regular chemical rriers without being stopped. This can be pre- nted by injecting into the bottom around the shell- h beds, to a depth of several inches and at deter- ined distances from each other either plugs consist- g of treated sand or oil and chemicals alone. This aterial injected in bottom soil and slowly oozing out, ould present an effective barrier against burrowing rms. Under certain circumstances it may be even ore effective than the regular type of barrier con- sting of treated sand placed directly on the bottom.

To us it is clear that we have now in our posses- on the basic principle of a method by means of hich the age-old problem of protecting shellfish eds from predators can be solved. Nevertheless, we now that our studies represent only the first few steps owards achieving complete control of the enemies y using this method and that many secondary prob- ems have to be solved before it can be commonly sed. Among these problems are the following:

Determine the effects of different chemicals used n barriers and different concentrations of these chem- cals on the rate of water pumping, feeding and other spects of the physiological behavior of mollusks, uch as clams, oysters, scallops and mussels. Deter- ine if some of the substances used in the barriers ccumulate in the body tissues of these mollusks, affect heir palatability or render them undesirable or dan- erous as food.

Determine the effects of the substances used in arriers on the gonad development of the mollusks nd on the rate of growth and survival of their larvae. Studies also should be carried on to find the effects of hemicals on the growth of juvenile bivalves.

Determine the effects of the chemicals upon the growth of representative forms of micro-organisms, which are used as food by bivalves, their juveniles and larvae.

Conduct observations on intensity of setting of oysters and other bivalves in areas surrounded by chemical barriers. Similar observations should also be made on setting of other organisms, including barnacles, tunicates, flatworms, etc. Compare intensity of setting in these areas with that in control zones.

Compare the survival and rate of growth of oyster set and other organisms in barrier-surrounded beds with those in control areas.

Determine the effects of the chemicals upon commercially-important forms inhabiting or found in the vicinity of treated areas. These forms should include fishes, especially flatfish, and also lobsters, blue crabs and other important crustaceans.

Several important physical aspects of the method should be solved before it can be put into general use. The size and quality of the sand and gravel particles and other substances which could be used to carry oil to the bottom and retain it there as a barrier are obviously important and should be determined.

The width of the barriers necessary to stop such enemies as starfish, crabs and drills under different ecological and hydrographical conditions should be ascertained. The length of time that barriers remain chemically active under different conditions has to be established.

Development of an apparatus for laying on the bottom chemical barriers cheaply but properly, and another apparatus for injecting mixtures of sand and chemicals in the upper stratum of the bottom to stop the movements of such burrowing gastropods as **Polinices** is an important part of the over-all program.

Since the method of incorporating substances in heavy oils and depositing them on the bottom with the help of sand or other carriers is rather simple, it may have other applications. For example, we suggest using it to determine if **Dermocystidium,** a widespread fungus disease of southern oysters, can be controlled by incorporating water soluble fungicides in heavy oils and surrounding oyster beds with belts or bands of this mixture. By using this approach or its variations, it may be possible to create concentrations of fungicides over oyster beds strong enough to control this fungus but not harm the mollusks. Since **Dermocystidium** is absent in our waters, we suggest that some of our colleagues in the South, especially the Gulf of Mexico, where **Dermocystidium** is abundant, undertake this study. If the method works,

lions of bushels of oysters will be saved in the f of Mexico alone each year.

The principle outlined above should also be tried ascertain if some of the substances will prevent ing of **Stylochus** larvae without harming those of ters or other useful forms.

In addition to the field applications mentioned ove, the principle of adding certain substances to avy oils can probably be used in laboratory and chery operations to keep worms, crustaceans, barcles and other organisms from setting in hatchery ys containing small clams or oysters. It is also ssible that by incorporating certain fungicides and ctericides in oils and placing these oils in containers rough which water passes before entering hatchery oughs, juvenile mollusks, many of which are susptible to a number of diseases, can be kept free of ngus and bacterial epidemics.

In conclusion, may we offer our sincere thanks to Mr. John F. LesVeaux of the Niagara Chemical Divion, Food Machinery and Chemical Corporation, hose advice, cooperation and help during these udies were invaluable, and whose willingness to proide us with numerous samples for our screening udies was a great help in the development of this ethod.

Since the date at which the above report was preented, work on the development of chemical barriers was continued and extended into Long Island Sound proper. One such barrier was established near Charles Island on the State spawning bed where a large area was surrounded by a wide path of sand mixed with orthodichlorobenzene. Prior to the creation of the barrier, the area to be protected was cleaned of starfish by SCUBA divers. After the barrier was laid, dyed starfish were deposited at various points inside and outside the experimental area, to follow their movements and determine whether they could travel over the barrier.

Additional experiments, consisting of covering entire areas with chemically-treated sand, were begun late in the summer. In New Haven Harbor four 1-acre plots (100 x 432 feet each) with 50-foot strips between them were treated on Lot 152 and four similar plots, on Lot 172. In each case, one plot was left untreated as a control, while the other three plots received different quantities of chemically-treated sand.

In the Westport district, an area comprising a 5-acre plot on Lot 1030 was treated with 15 cubic yards of sand, which was mixed with orthodichlorobenzene, tetrachlorobenzene and Sevin. The sand was spread from the barge with the same piece of machinery that is used to spread it on icy roads during the winter.

All these experiments are still in progress and we plan to report the results as soon as our studies are completed. It must be remembered, however, that experiments of this nature require long periods.

The State Shell Fish Commission and several oyster companies helped us considerably in our Long Island Sound studies. The Commission not only provided us with experimental grounds near Charles Island, but also participated in the laying of the chemical barrier there. Furthermore, when our schedule became too crowded and our research boat was unable to handle all the assignments that came along because of a crash program, the State boat took over the responsibilities of attending to our set collectors in Long Island Sound, collecting plankton samples and performing other tasks which are usually carried on during the oyster setting season.

Several oyster companies, especially F. Mansfield & Sons Company and Sealshipt Corporation, offered us their grounds for experiments and rendered other help.

Finally, various groups of Region 3 of the Bureau of Commercial Fisheries closely cooperated with us all summer. SCUBA divers, who helped us to analyze the conditions existing on the chemically-treated bottoms, were especially helpful.

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se of Chemicals To Control hellfish Predators

Abstract. Many enemies of such bivalves s oysters and clams can be controlled by he use of heavy oils, such as orthodichlo-obenzene. These oils are mixed with dry and, or other inert carriers, to anchor hem in place on shellfish beds. Effects of he treatment may be increased by incor-orating other chemicals in heavy oils. The treated sand can be used to surround he shellfish beds, thus preventing the en-rance of the enemies, or it may be spread ver the infested areas, killing the enemies nd, under certain conditions, stopping heir larvae from reinvading the beds. Snails, starfish, and, in some instances, crabs can be controlled in this manner.

The need for controlling enemies of mollusks has been obvious ever since people began to harvest them for food (*1*). In this report we describe the principle of a new, simple, but effective chemical method which may help solve the problem, although, because it is still in the experimental stage, it is too early to recommend its commercial application.

The method is devised to prevent boring gastropods, starfish, crabs, and other enemies of bivalves from invading shellfish beds, and also to render these beds unsuitable for their existence. To prevent invasion, beds are surrounded with "barriers" or "belts" of sand or some other inert carrier treated with chemicals which either stop, repel, or kill predators. Clearing an area of predators and preventing setting of their larvae can be accomplished by spreading chemically treated sand over the bottom.

While testing numerous compounds on marine invertebrates, we found that heavy chlorinated oils, such as trichloroethylene, orthodichlorobenzene, paradichlorobenzene, trichlorobenzene, and tetrachlorobenzene will repel, stop, cause swelling in, or even kill boring gastropods, such as oyster drills, *Urosalpinx cinerea* and *Eupleura caudata*, and those of the genera *Polinices*, *Busycon*, *Thais*, and others. We realize the serious danger that may be created by indiscriminate use of chemicals, but fortunately the oils that we have selected are insoluble or only slightly soluble in water and, therefore, they should not pose a pollution problem.

Although barriers of heavy oils and sand stopped gastropods, their efficiency was increased by incorporating some other compounds in the oils. One of these is Sevin (1-naphthyl-N-methylcarbamate), an insecticide which is relatively nontoxic to mammals but is highly toxic to gastropods and to crabs, another important enemy of shellfish. Still another enemy, the starfish *Asterias forbesi*, can be stopped by barriers consisting of sand, heavy oils, and certain compounds, such as 2-chloro-1-nitropropane. Eventually, several formulas were developed that can stop the movements of boring gastropods, starfish, and under certain conditions, crabs. One such mixture was orthodichlorobenzene containing 2-chloro-1-nitropropane and Sevin (*2*).

There are many conditions that determine the effectiveness of our methods. In barriers, the width, the proportion of sand, the oils and other chemicals, and the concentrations of these chemicals per unit of surface are of importance. The general condition of the bottom, silting, and the velocity of currents should also be considered. We may give, nevertheless, some illustrations of the effectiveness of certain formulas. In one of our experiments a barrier only 8 in. wide, composed of sand and orthodichlorobenzene, remained effective against drills from 1 February 1959 through March 1960. During this time not a single drill crossed the barrier, although new groups of ten drills were placed in the experimental trough every 2 weeks.

Virtually no starfish crossed barriers only 3 feet wide composed of sand, orthodichlorobenzene, and 2-chloro-1-nitropropane or similar mixtures. In nature, because starfish may be helped to move along the bottom by currents, barriers should be considerably wider.

All the heavy oils tested caused extreme swelling in gastropods. Affected in this way they were unable to move, and some soon died. The first sign of distress shown by starfish upon coming in contact with barriers was usually a curling of the tips of their rays. Disintegration of the lower surfaces soon began, and casting of the rays sometimes followed.

Affected crabs first lost equilibrium and later went into convulsions. However, orthodichlorobenzene alone usually does not seriously affect crabs. To stop them, other chemicals, principally insecticides, should be added to the oils. Thus, narrow barriers composed of sand and orthodichlorobenzene are relatively safe for crabs and can be used to control gastropods in areas where crabs are commercially important.

Spreading chemically treated sand over oyster beds is another method for controlling shellfish enemies. This method may kill most oyster drills on the infested bottoms. Field experiments to test this method further are now in progress. The same method may kill ready-to-metamorphose larvae of starfish, certain gastropods, and crabs and worms, which, being pelagic, can float over the barriers. Adult and recently set starfish can be attacked by spreading treated sand over beds. Sand grains will imbed in the membrane covering the starfish's body and cause its decomposition.

Because certain gastropods, such as the clam-killing snail *Polinices*, are able to move under several inches of bottom soil, they may not be stopped by the above-described methods. However, by injecting into the bottom soil plugs of treated sand, or oil alone, it may be possible to create an effective, three-dimensional barrier.

Since the principle of our method is rather simple, it may have other applications. For example, it might be possible to control *Dermocystidium*, a widespread fungus disease of southern oysters, by incorporating water-soluble fungicides in the oils and surrounding oyster beds with belts of these mixtures or spreading them over entire areas where diseased oysters are found.

Spreading chemically treated sand over oyster-growing bottoms may eliminate the mud shrimp *Upogebia* and the predaceous flatworm *Stylochus*. Moreover, variations of the basic method could be tried to reduce the population of fresh-water snails such as *Oxytrema*, intermediate hosts of parasites causing numerous diseases in fish. Finally, the method may be helpful in the control of schistosomiasis by destroying snails which act as intermediate hosts of human schistosomes.

We believe that we have now the basic principles of a method by means of which the age-old problem of protecting shellfish beds from predators can be solved. We realize, nevertheless, that our studies represent only the first steps toward achieving full control of these enemies and that many secondary problems have to be solved before the method can be recommended for general use. For example, it will be necessary to determine the effects of the chemicals on aquatic communities in general and ascertain if some of the substances used accumulate in the body tissues of mollusks, such as oysters, rendering them undesirable or dangerous as food (*3*).

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3. We wish to thank John F. LesVeaux of the Niagara Chemical Division, Food Machinery and Chemical Corporation, for providing numerous samples of chemical compounds for our "screening" studies.

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Some Factors Influencing Seasonal Changes in Angler Catch in a Minnesota Lake[1]

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ABSTRACT

An investigation was undertaken in a small Minnesota lake to determine the relationship between angler success for northern pike *(Esox lucius)*, bluegill *(Lepomis macrochirus)*, and crappie *(Pomoxis nigromaculatus)* and food availability and food selectivity by these species. Fishing success was determined by creel census and food selectivity by stomach analysis of angler-caught fish. Food availability was determined by bottom sampling and shore seining for small fish. Over a 3-year period anglers' catch was highest in June and lowest in late summer. Angling success was inversely related to food availability and food intake, but changes in physical and chemical factors did not appear to be related to rate of angler take.

INTRODUCTION

Fresh-water sport fisheries management is usually based on the assumption that availability of fish to anglers is constant throughout the angling season. Angler success, however, varies greatly during the course of a season in many warm-water lakes although netting surveys do not show corresponding changes in fish abundance. The fisherman's catch is usually highest in the early part of the summer and then becomes gradually less as the season progresses. It has been suggested that the mid-season slump is associated with an increase in available food which makes game fish less likely to be caught. The present study was undertaken in the spring of 1954 to test this hypothesis. Information required for this purpose was the relationship of foods selected by fish to angling success in terms of catch per unit of effort, and the relationship of foods selected by fish to food availability in the habitat. Linwood Lake, where a continuous creel census from 1952 through 1954 showed that the catch per unit of effort was highest early in the season and declined rapidly as the season progressed, was selected for study.

In addition to measurement of trends in catch rate, seasonal changes in quality and quantity of available food and food used by game fish were determined. Estimates of available food were made from bottom samples and seine hauls, and of food selection from stomach contents of the fish. Northern pike *(Esox lucius)*, bluegills *(Lepomis macrochirus)*, and black crappies *(Pomoxis nigromaculatus)*, the species most commonly taken by anglers, were checked.

A secondary objective of the study was to determine the relationship between angler success and the physical and chemical factors that show seasonal change. Water temperature, turbidity, pH, dissolved oxygen, and total carbonates were therefore compared throughout the summer season to catch rate.

Linwood Lake

Linwood is an ice-block lake of the Anoka sand plain which lies in the Mississippi drainage basin of southeastern Minnesota. It has an area of 765 acres and a maximum depth of 35 feet (Figure 1). Most of the lake is shallow with sandy bottoms and the littoral zone contains extensive growths of aquatic plants. The recreational development consists of two boat liveries and about 35 summer cottages along the northern shore. A thermocline is present from June to mid-September and in 1954 the surface temperature varied from 60° F. at the end of May to 77° F. in July and August. Oxygen was absent in the hypolimnion during most of the summer. Water analysis has shown that the lake is moderately fertile. A total of 23 species of fish has been recorded from 1954 seine hauls and Minnesota Department of Conservation records. Fish were netted with experimental gear in the summers of 1952-54 to obtain estimates of

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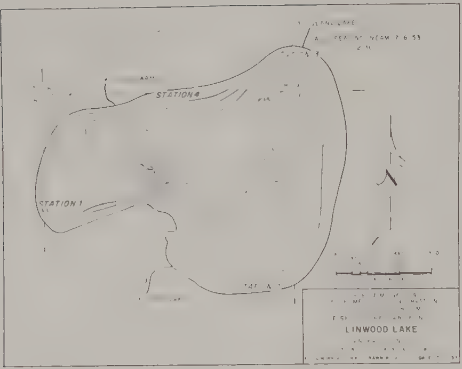

FIGURE 1.—Linwood Lake, Anoka County, Minnesota.

abundance (Table 1). In the 3 years of observation the average catch per 24-hour trap-net set dropped from 9.0 pounds in 1952 and 9.9 pounds in 1953 to 4.7 pounds in 1954. The fact that estimates of angler catch indicated a slightly higher total harvest in 1954 than in each of the 2 earlier years suggested that inadequate net sampling may have been responsible for the apparent decline in abundance.

Northern pike and crappies, the principal predator species in Linwood, are present in average and above average numbers, respectively, while the abundance of walleyes *(Stizostedion v. vitreum)* and largemouth bass *(Micropterus salmoides)* is low compared to other Minnesota lakes. The catch of sunfish per trap-net set is near the average for the state. Carp *(Cyprinus carpio)* were relatively abundant in 1946 when a rough-fish removal crew seined several thousand pounds from the lake but were not common in 1954. Bullheads *(Ameiurus spp.)*, suckers *(Catostomus commersoni)*, and dogfish *(Amia calva)* were present in low numbers.

TABLE 1.—*Weight of fish caught in experimental nets in Linwood Lake (1952-1954), expressed as pounds per net per 24-hour set*[1]

Item	1952	1953	1954	1954
Number of nets	32	40	8	12
Type of net	Trap	Trap	Trap	Gill
Northern pike	0.92	2.14	0.61	4.33
Walleye	0.80	0.60	0.70	0.87
Perch	0.01	0.01	—	0.26
Bluegill	1.43	1.95[2]	0.41	0.04
Pumpkinseed	0.26		0.06	0.03
Largemouth bass	0.06	0.07	0.32	0.16
Crappie	3.62	4.32	1.61	0.97
Others[3]	1.93	0.85	0.98	3.41
Total fish	9.03	9.93	4.69	10.07

[1] From data compiled by the Minnesota Department of Conservation.
[2] Sunfish were not separated by species in 1953.
[3] Includes bullheads, dogfish, suckers, and carp.

Average weight of individuals of most species remained substantially unchanged over the 3-year period. Since the average weight of walleye pike was about 5 pounds and no small walleyes were caught in nets or by anglers, it is believed that the few large walleyes caught in recent years were the remains of planted stock.

Age structures of the populations of northern pike, bluegills, black crappies, and largemouth bass were estimated from scales of angler-caught fish in 1954. With the exception of crappies most of the catch of these species was furnished by fish of the middle age groups. Northern pike and bass are first caught in significant numbers during their fourth year; bluegills reached good catchable size in the fifth growing season; and fish in their third year supplied a substantial proportion of the total crappie catch in late summer. Since third-year crappies outnumbered other age groups in the catch during 1954 the 1952 year class probably was unusually strong and contributed more to the catch than an average year class. The 1951 year class contributed little and was probably weak Growth rates of the various species, estimated from average lengths of age groups, were found to be slightly greater than statewid mean growth rates.

Current regulations in Linwood permit year-around angling for sunfish and crappies winter angling for walleyes and northern pike winter spearing of northern pike, and summer angling for pike and other species. Between 1910 and 1945 hatchery-reared fry and fingerlings of walleye and northern pike crappies, sunfish, and largemouth bass were planted. Rough fish, especially carp and dogfish, have been removed with seines or trap at various times.

Catch by anglers

Data from the creel census operated by th Minnesota Department of Conservation fro 1952 through 1954 on Linwood Lake to d termine fish population structure, angler catc and the value of management practices, we used in the present study. The census su lied estimates of the number of fishermen, umber of fishing trips, hours of fishing efort, total catch, and catch composition by pecies and sizes (Moyle and Franklin, 1953) nd was based on a stratified sampling pattern hich included only certain days in a census eriod. Summaries were based on a 10-week eriod. On each census day counts of shore nd boat fishermen were made at 2-hour interals and clerks attempted to contact at least alf of the fishing parties at trip completion. stimates of total catch based on these samling methods had some limitations. Weather robably introduces the greatest error. If everal census days in a period had inclement eather, the fishing load was reduced and the alculated fishing intensity was lower than the eal value. In the present study unexpanded ensus information only was used in comparions with food availability and food selectivty.

As previously mentioned the principal anger-caught fish in Linwood are northern pike, luegills, and crappies. Yellow perch *(Perca lavescens)*, pumpkinseed *(Lepomis gibbous)*, bullheads *(Ameiurus spp.)*, largemouth ass, and walleye pike were also taken. In 952-1954 the latter group made up about percent of the total numbers caught.

The summer creel census began May 15 in 952 and 1953 and in the last week in April n 1954. Thirty-eight days were checked in he summer of 1952, 64 days in 1953, and 58 days in 1954. Angler catch of northern pike, crappie, and sunfish, and of the three species combined was summarized by semi-monthly intervals (Table 2, Figure 2). The catch rate for sunfish was highest in June and for crappies it was highest in July. More northern

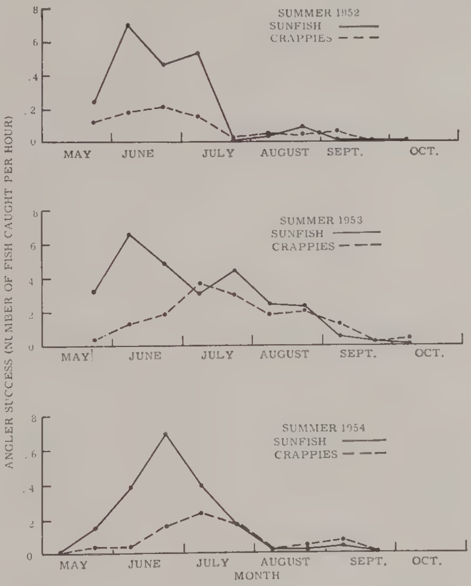

FIGURE 2. — The average number of sunfish and crappies caught per angler-hour at Linwood Lake in 1952, 1953, and 1954, as shown by census information.

ABLE 2.—*Estimated average numbers of northern pike, sunfish, and crappies taken per angler-hour at Linwood Lake during the summer seasons of 1952, 1953, and 1954*[1]

Year and Species	Average numbers of fish caught per angler-hour									
	May	June		July		August		September		October
	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-15
952										
Northern pike	0.08	0.05	0.03	0.02	0.04	0.03	0.05	0.06	0.04	0.00
Sunfish	0.24	0.70	0.46	0.53	0.00	0.03	0.09	0.01	0.00	0.00
Crappie	0.12	0.19	0.21	0.15	0.21	0.04	0.04	0.06	0.01	0.00
Total	0.44	0.94	0.70	0.70	0.25	0.10	0.18	0.13	0.05	0.00
953										
Northern pike	0.17	0.05	0.03	0.01	0.02	0.04	0.02	0.05	0.07	0.07
Sunfish	0.32	0.66	0.48	0.30	0.44	0.24	0.23	0.05	0.02	0.00
Crappie	0.03	0.13	0.19	0.37	0.30	0.18	0.20	0.13	0.02	0.04
Total	0.52	0.84	0.70	0.68	0.76	0.46	0.45	0.23	0.11	0.11
954										
Northern pike	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.04	0.23
Sunfish	0.15	0.38	0.69	0.39	0.16	0.02	0.02	0.04	0.00	0.00
Crappie	0.04	0.04	0.16	0.23	0.17	0.03	0.04	0.07	0.01	0.00
Total	0.23	0.44	0.86	0.63	0.34	0.06	0.07	0.11	0.05	0.23

[1] Data are from census records of the Minnesota Department of Conservation.

pike were caught at the beginning and near the end of each season than in midsummer, but the low rate of catch does not permit a reliable assessment of seasonal changes. Average catch per hour of pike and panfish combined was highest in June and July of each season. Estimates of total numbers and pounds of all fish taken by the summer anglers, 1952-1954, (Moyle and Franklin, 1953, 1954, and 1955) indicate that the grand totals, and in many cases the totals for individual species, are very similar from year to year (Table 3). Summer angling effort in 1954 was considerably greater than in the 2 previous years of the census, but this increase was not accompanied by larger catches (Tables 2 and 4).

ANGLER CATCH IN RELATION TO AVAILABLE AND SELECTED FISH FOOD

Available fish food has been measured in various ways in previous studies. Surber (1929) stated that fish selected food on the basis of relative abundance and conspicuousness. Hess and Swartz (1941) defined available food as "organisms which are capable of being eaten by a fish if he so desires". In the Linwood study all animal food of edible size was considered to be available food.

Food availability and angler catch

Considerable variation in the shallow-water habitat of Linwood was noted, especially with respect to vegetation types. Since it was desirable to obtain estimates of available food that were representative of the entire lake, four stations characteristic of the principal vegetation and bottom types were used for sampling of the bottom fauna and forage fish (Figure 1).

TABLE 4.—*Estimated fishing effort by summer anglers at Linwood Lake, 1952-1954, expressed as total man-trips, total man-hours, hours per acre, and average length of each trip*[1]

Year	Man-trips	Man-hours	Hours per acre	Hours per trip
1952......	11,449	43,970	57.4	4.4
1953......	11,023	39,239	51.3	3.7
1954......	15,918	54,172	70.8	3.7

[1] Data are from creel census records of the Minnesota Department of Conservation.

Bottom organisms.—Bottom samples were taken with a Petersen dredge in water 2 to 5 feet deep at approximately semi-monthly intervals from May 1 to October 15, 1954. Samples were washed through a 40-mesh sieve, insect larvae were identified to order or family, and other organisms to class or order. Organisms in each group were counted and the volume of all animals in each sample, exclusive of mollusks, was measured by alcohol displacement. Samples taken on the same day at the four stations were combined and summarized by months to provide an appraisal of seasonal trends in numbers (Table 5). Total number of bottom organisms was at an intermediate level in May 1954, and decreased slightly in June following emergence of insects. After the June low the numbers gradually increased to a peak in September. This general pattern of invertebrate abundance was similar to one reported from a Michigan lake (Ball, 1948).

TABLE 3. -*The summer angler catch taken from Linwood Lake, 1952-1954, expressed as total numbers an pounds of fish*[1]

Item and year	Species								
	Northern pike	Sunfish	Crappie	Perch	Bullhead	Bass	Walleye	Other[2]	Total
1952									
Number......	2,102	16,385	6,848	1,209	417	302	10	—	27,273
Weight......	4,859	5,410	2,348	242	357	770	60	—	14,046
1953									
Number......	2,043	15,033	8,455	527	335	208	43	—	26,644
Weight......	4,013	4,474	2,514	54	269	455	187	—	11,966
1954									
Number......	1,127	19,291	6,309	509	380	221	6	7	27,850
Weight......	2,756	8,148	2,066	62	567	511	38	21	14,169
Mean number..	1,757	16,903	7,204	748	377	244	20	2	27,253
Mean weight...	3,876	6,011	2,309	119	398	579	95	7	13,394

[1] Minnesota Department of Conservation estimates based on creel census.
[2] Includes bullheads, carp, and suckers.

ABLE 5.—*Available food in Linwood Lake estimated from bottom samples and expressed as percentage of total number of organisms present during each month—1954*

Item	May	June	July	August	September	October
phemeroptera	0.2	1.3	34.2	4.7	0.7	1.0
donata[1]	—	0.4	0.1	0.4	0.3	0.3
richoptera[2]	1.0	1.1	0.8	6.6	3.1	8.8
oleoptera[3]	—	—	0.8	0.1	0.1	—
hironomidae	90.8	85.2	19.3	14.4	10.2	16.6
abanidae	—	0.8	0.5	1.1	0.2	0.1
yalella	2.1	3.1	32.6	57.7	74.0	55.9
ydracharina	—	—	0.1	T[5]	T	—
irudinea	1.6	1.9	8.3	5.2	2.8	1.6
ligochaeta	3.2	5.8	2.9	2.3	1.2	4.5
phaeriidae[4]	—	—	—	1.7	1.9	2.0
astropoda[4]	—	—	—	4.4	3.1	8.2
urbellaria	0.7	0.2	0.1	1.3	2.3	1.0
ematoda	0.4	0.2	0.3	0.1	0.1	—
otal	100.0	100.0	100.0	100.0	100.0	100.0
olume in cubic centimeters per square foot[6]	1.3	0.4	0.9	1.0	1.4	1.4

[1] Principally Coenagrionidae.
[2] Principally Leptoceridae (caddis flies were removed from cases).
[3] Principally Chrysomelidae.
[4] Not tallied with August.
[5] Trace.
[6] Exclusive of Mollusca.

Forage fishes.—A 30-foot, ¼-inch mesh seine, with a lining of 5/32-inch netting in the center section, was used to make semimonthly hauls at the four stations during the summer season. Each haul covered approximately 3,000 square feet. All young-of-the-year (O-group) fish taken were preserved in formalin while older fish were counted and a representative sample saved. Some catchable-size fish were retained for stomach analysis. Fish were separated into O-group and older fish by species, and the number and average total length in millimeters of each group were determined. Forage-size fish from seine hauls at all stations were combined and summarized to obtain the average number of each species per 10,000 square feet of surface area (Tables 6 and 7). "Forage-size" was arbitrarily

TABLE 6.—*Average numbers of fish seined per 10,000 square feet of surface area in Linwood Lake, May through July, 1954*[1]

Species	Age	Month and day						
		May 8	June 12	June 18	June 29	July 9	July 15	July 27
Spottail shiner	yy[2]	—	—	205	48	121	159	1
Spottail shiner	ad[3]	850	3	—	—	—	—	—
Golden shiner	yy	—	—	—	—	—	2	2
Bluntnose minnow	yy	—	—	—	2	23	16	242
Bluntnose minnow	ad	6	—	17	5	1	7	5
Fathead minnow	ad	—	1	2	2	—	—	—
Carp	yy	—	—	—	—	—	3	1
Johnny darter	yy	—	—	2	8	35	32	128
Johnny darter	ad	—	18	5	—	1	10	4
Iowa darter	yy	—	—	—	2	3	—	9
Iowa darter	ad	—	—	1	1	—	—	—
Killifish	yy	—	—	—	—	2	11	31
Killifish	ad	—	24	6	4	6	7	5
Yellow perch	yy	—	2	1	1,350	564	369	239
Yellow perch	I	343	8	54	161	240	244	206
Sunfish	yy[4]	—	—	—	12	1,771	805	525
Bluegill	I	—	2	1	—	—	2	3
Pumpkinseed	I	—	—	—	8	1	1	—
Largemouth bass	yy	—	—	1	25	30	122	64
Largemouth bass	I	2	—	—	1	1	—	—
Northern pike	yy	—	—	—	1	1	3	—
Black crappie	yy	—	—	—	1	5	2	2
Black crappie	I	5	—	—	—	—	—	—
Brown bullhead	yy	—	—	—	—	—	2	3
Tadpole madtom	yy	—	—	—	—	—	—	1
Total (all fish)		1,206	58	295	1,631	2,805	1,797	1,471
Total (yy fish)		—	2	209	1,449	2,555	1,527	1,248

[1] Fish from all four sampling stations are combined and the average numbers are weighted for all stations. Fish, other than minnows, of more than one annulus are not included in the table.
[2] Young-of-the-year.
[3] Adult.
[4] Pumpkinseeds and bluegills were combined in early post-larval stages because they were not readily separable.

chosen as the length at I-annulus or less in the case of larger species such as sunfish, carp, and perch, but included all sizes and ages of the minnows and other small species. This choice was based on sizes of fish found in stomachs of game species.

Young-of-the-year bluegills and pumpkinseeds during early stages were grouped together because they were not easily separated in the field, but young-of-the-year and I-annulus fish were tallied separately since they differed in seasonal abundance. The total number of O-group fish of a species rises to a maximum at some period during the season, depending upon spawning time, and then gradually drops. Older fish, however, continually decline in numbers as the season progresses.

The number of O-group fish taken on a particular date did not always agree with what might be predicted from the preceding sample. Such apparent changes in abundance may have been due in part to sampling error, but may also have been actual changes caused by the addition of fish from late hatches. To minimize error the samples were combined by monthly intervals (Table 8). Since only O-group fish were numerous enough in all months to show the trends in seasonal abundance, older fish were not included in the monthly summaries. Peaks of abundance of spottail shiners and yellow perch were somewhat earlier than the peak of sunfish, while the peak for the latter was earlier than that for bluntnose minnows. Average abundance of all young fish combined was at a maximum in July.

Assuming that seine-caught fish were caught in proportion to their abundance, sunfish and yellow perch were the most abundant species present. Although crappies rank high on the list of angler-caught fish in Linwood, few young crappies were found in seine catches, possibly because there was limited survival of spawn in 1954.

While bottom samples and seine hauls provide some measure of available food in a lake, these sampling methods have limitations. All microscopic aquatic invertebrates were not caught in the Petersen dredge, as is later shown by stomach analyses. Other animals were probably not always taken in proportion to their abundance because vegetation sometimes prevented the dredge jaws from closing

TABLE 7.—*Average numbers of fish seined per 10,000 square feet of surface area in Linwood Lake, August through October, 1954*[1]

Species	Age	Month and day						
		August 14	August 28	September 7	September 17	September 24	October 5	October 17
Spottail shiner	yy	—	3	—	4	—	5	4
Spottail shiner	ad	—	1	—	—	—	—	—
Golden shiner	yy	1	9	—	2	27	—	—
Bluntnose minnow	yy	497	86	221	22	19	7	1
Bluntnose minnow	ad	8	—	—	—	—	—	—
Fathead minnow	yy	—	—	—	—	2	1	—
Fathead minnow	ad	1	—	—	—	1	—	—
Carp	yy	1	1	—	—	1	—	—
Johnny darter	yy	155	10	52	30	22	24	4
Johnny darter	ad	1	1	—	—	1	1	—
Iowa darter	yy	23	—	14	3	2	2	1
Iowa darter	ad	—	—	1	—	—	—	—
Killifish	yy	68	24	222	42	15	14	1
Killifish	ad	14	2	44	8	1	1	—
Mud minnow	yy	—	1	1	1	—	2	—
Yellow perch	yy	354	72	270	335	69	75	32
Yellow perch	I	102	120	80	86	180	79	26
Bluegill	yy	—	—	1,107	617	991	564	445
Pumpkinseed	yy	856[2]	771[2]	50	44	90	10	6
Bluegill	I	—	3	—	—	8	—	—
Pumpkinseed	I	—	8	7	—	6	—	1
Largemouth bass	yy	38	39	28	20	14	10	7
Northern pike	yy	1	2	3	2	1	1	2
Black crappie	yy	1	—	4	—	1	—	1
Black crappie	I	5	—	—	2	2	—	—
Brown bullhead	yy	1	1	—	1	2	—	—
Yellow bullhead	yy	4	—	—	—	—	2	—
Tadpole madtom	yy	—	—	—	—	—	4	—
Total (all fish)		2,130	1,154	2,104	1,219	1,455	802	531
Total (yy fish)		2,000	1,019	1,972	1,123	1,256	721	504

[1] See explanatory notes in Table 6.
[2] See note 4, Table 6

TABLE 8.—*Average numbers of O-group fish seined per 10,000 square feet of surface area in Linwood Lake each month in the 1954 season*

Item	June	July	August	September	October
Area seined (square feet)	50,000	39,000	20,000	34,000	26,000
Spottail shiner	116	106	1	1	4
Golden shiner	—	1	5	12	—
Bluntnose minnow	1	77	310	71	4
Killifish	—	12	48	76	7
Johnny darter	4	58	89	32	14
Iowa darter	1	4	12	5	1
Yellow perch	486	426	226	205	53
Bluegill	—	—	—	901	502
Pumpkinseed	4[1]	1,180	817	65	8
Black crappie	1	3	1	1	1
Largemouth bass	10	65	38	19	8
Total	623	1,932	1,547	1,388	602

[1]Bluegills and pumpkinseeds are combined prior to September.

tightly. In addition, this gear does not effectively sample small organisms like amphipods which live just off the bottom. Thick growths of aquatic plants cut seining efficiency at times and during the latter part of the season it became difficult at two stations to complete a haul without losing part of the catch. Since these sources of error are known to be present, it is believed that the estimates are adequate only for showing general trends.

Influence of food availability on rate of catch.—If angler success varies inversely with food availability, a comparison of creel census returns and trends in food abundance should show this relationship. A comparison of trend in fishing success and food availability was made with the 1954 data (Figure 3). Fishing success is expressed as combined numbers of sunfish, crappies, and northern pike caught per hour of fishing. Available food is expressed as numbers of O-group fish caught per 1,000 square feet seined and as volumes of bottom invertebrate fauna per square foot of bottom sampled. These data show that a reciprocal relationship existed between total food supply and angler catch during the summer season. In the middle of June, when available food had fallen to its lowest level, angler success approached the seasonal peak. In mid-July, as the available food supply climbed, the catch of fish was reduced. The numbers of O-group fish declined after mid-July, but their rapid increase in weight increased the food supply during this period.

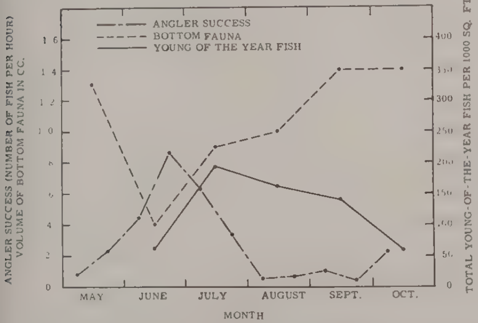

FIGURE 3.—Angler success and available food in Linwood Lake during the 1954 season. Food does not include mollusks.

Food utilization and angler catch

Stomachs of fish caught by anglers were collected to compare food utilization and angler catch rate. During the latter part of the summer fishing season, when angler success was low, some stomachs were obtained from seine-caught fish. No food other than fish was found in pike stomachs, while crappies contained both invertebrates and fish. Bluegills fed on both invertebrates and plants. Volumes of fish and invertebrate food were measured separately by alcohol displacement and food identified as bait was discarded. The type of plant food found in bluegill stomachs was noted and an estimate of its proportion of total food was made. All organisms in stomachs were identified and counted. Invertebrates were identified, where possible, to the same groups used in identification of bottom-sample fauna; fish were identified to species and note was made of ages (*i. e.*, O-group or older). Digestion in some cases prevented species identification of fish, but usually size indicated whether or not they were from the current year class.

Northern pike.—Stomachs from 45 northern pike were obtained during 1954. Early in the season samples were collected from angler-caught fish, but later most specimens were obtained from seine hauls. Although the number of analyses was small, a definite change in the size of fish eaten was noted as the season progressed. In May only fish older than young-of-the-year were selected; in mid-season both O-group and older fish were utilized; and in the latter part of the season pike food consisted almost entirely of O-group fish (Table 9). Catch rate of pike was highest when the proportion of stomachs containing food was lowest.

Most of the fish used by pike in May were I-annulus and older perch, with the former predominating. Young-of-the-year fish of edible sizes had not yet appeared in the lake. From late June to mid-September perch continued to be the principal species taken with O-group fish being substantially used. In late September and October O-group perch and sunfish were taken in nearly equal numbers with perch supplying the greater volume because they were larger in size.

The size of fish selected appeared to be dependent upon relative availability. Small fish of the 1953 year class were selected when they were comparatively plentiful, but when O-group fish became abundant the pike used them in increasing numbers. Fish older than O-group were less available as they became too large to be eaten and as their numbers declined.

Food habits of pike in Linwood are similar to those reported by other workers (Pearse, 1918; Forbes and Richardson, 1920). Frost (1954) showed that northern pike in an English lake fed almost entirely upon fish, with perch occurring in the diet at all times but predominantly from May to October. She attributed this seasonal variation in the selection of perch to changes in the habits of prey species and concluded that abundance and availability rather than selection by pike determined which fish were eaten. Stomach analyses and seine-haul data suggest that these factors also determined food utilization by Linwood pike.

Bluegill sunfish.—Stomachs from 104 bluegills were collected from the 1954 angler catch. Different organisms found in the stomachs were counted only, but total volume of contents was measured in all cases. Immature insects (principally chironomids and trichopterans), hydracharinids, and cladocerans were the most important animal food in the diet (Table 10). Cladocerans, among which *Daphnia* spp. predominated, were of major importance only in the early part of the season, while hydracharinids were heavily utilized in both May and July. Mollusks were taken in small numbers throughout the summer.

As summer progressed bluegills ingested increasing amounts of rooted plant material, primarily narrowleafed pondweeds *(Potamogeton* spp.) (Figure 4). The average volume of food taken by bluegills rose as the season advanced, but the volume of invertebrates dropped while the plant intake rose sharply. In late July the average total volume of invertebrate food was below that of May. The diet of bluegills reported by other workers (Forbes and Richardson, 1920; Ball, 1948) agrees closely with the Linwood results.

Condition factor (C) was calculated for all bluegills included in food studies from the formula:

$$C = \frac{100{,}000W}{L^3},$$

where W is fish weight in pounds and L is total fish length in inches. The condition factor rose from 80 in late May to about 85 in

TABLE 9.—*Species and sizes of fish selected by northern pike in Linwood Lake during the 1954 season*

Date interval	Total fish	Empty stomachs	Fish in pike stomachs	
			Young-of-the-year	I–Annulus or over
May 15-30	21	10		12 perch 5 other[1]
June 26-September 17	9	2	3 perch 1 sunfish 2 other	3 perch 3 other
September 24-October 17	15	4	5 perch 5 sunfish 5 other	1 bullhead

[1] Includes unidentified fish, most of which were minnows.

TABLE 10.—*The animal food of catchable-size bluegills in Linwood Lake during the 1954 summer season, expressed as number and percentage of organisms per stomach*

Item	May		June		July	
	Number	Percentage	Number	Percentage	Number	Percentage
Total stomachs	12		36		57	
Empty stomachs	0		3		4	
Ephemeroptera	T[1]	T	0.8	1.3	0.5	0.5
Odonata	0.3	0.1	0.5	0.8	0.1	0.1
Hemiptera	—	—	0.2	0.3	T	T
Trichoptera	4.5	1.6	10.9	18.1	4.8	4.7
Coleoptera	—	—	0.4	0.7	0.2	0.2
Chironomidae	18.0	6.5	15.4	25.5	23.5	23.1
Chaoborinae	16.9	6.1	T	T	T	T
Ceratopogonidae	T	T	0.5	0.8	T	T
Cladocera	94.5	34.0	3.8	6.3	—	—
Hyalella	7.3	2.6	1.7	2.8	6.9	6.8
Hydracharina	135.2	48.6	19.8	32.8	57.4	56.5
Copepoda	—	—	0.4	0.7	T	T
Ostracoda	—	—	—	—	0.5	0.5
Hirudinea	T	T	T	T	—	—
Sphaeriidae	—	—	3.2	5.3	2.4	2.4
Gastropoda	1.5	0.5	2.8	4.6	5.3	5.2
Total	278.2	100.0	60.4	100.0	101.6	100.0

[1] Trace.

June and then fell to 80 again in early July. In the last half of July it rose slightly to about 82. Spawning activity in late June and early July probably caused the drop in average condition, but the slight rise in late July indicated that bluegills were subsisting well on a predominantly vegetable diet.

Little relationship is shown by a comparison of invertebrates taken in bottom samples (Table 5) and food selected by bluegills in 1954 (Table 10). Certain organisms, such as plankters, occurred regularly in stomachs but were either not caught at all in the bottom sampler or were inadequately sampled.

In the last half of May a total of eight food items was selected by bluegills in significant amounts; in June, 13 items; and in July, 10 items. From May 15 to July 31 the number of items taken in bottom samples increased slightly. The reduction in the number of animal food items eaten from June through July coincides with the increased consumption of vegetation at this time. Certain foods such as chironomids, amphipods, and hydracharinids apparently were selected by bluegills in preference to foods such as turbellarians, nematodes, and oligochaetes. Trichopterans and chironomids were two of the more stable food sources for bluegills until late July when abundance of all invertebrate organisms in stomachs diminished. The high abundance of chironomids in May apparently had little effect upon the degree of their utilization.

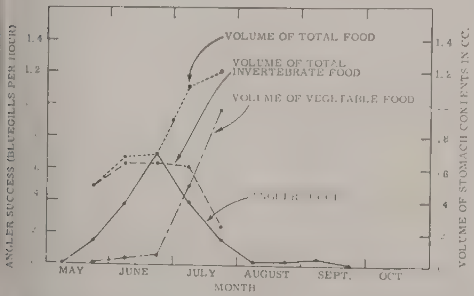

FIGURE 4. — The food intake and the catch per angler-hour of bluegills in Linwood Lake during the 1954 season.

While cladocerans, amphipods, and hydracharinids provided a source of food for bluegills, they varied widely in abundance. As in the case of chironomids, amphipods were not utilized in proportion to their numerical abundance. In July, when there were 84 amphipods per square foot of bottom, an average of only 7 was found per bluegill stomach or about the same number as in May when there were less than 5 per square foot. Although hydracharinids were not sampled with the bottom dredge, the numbers present in stomachs suggested that their abundance was occasionally great although highly variable.

In order to determine the relationship between angler success and gross changes in food intake by bluegills, the catch was compared to relative amounts of animal and plant material taken during the period (Figure 4). Of the two primary food types vegetation alone appears to be associated with angler success. In July a sharp increase in the selection of vegetation coincided with a rapid drop in fish catch. In the period covered the proportion of animal food in the diet showed no marked relationship to catch rate. Because vegetation formed such a large part of the mid-season bluegill diet, the trend in total food followed the trend of the plant intake. The total food ingested rather than the amount of one type may exert the greatest influence upon angler success, so that when food volume exceeds a certain level the probability of a bluegill taking a baited hook is reduced.

Black crappies.—Stomachs from 156 catchable-size crappies were collected in 1954 and the occurrence of each major group of food organisms was summarized by month (Table 11). Fish present in stomachs were identified to species where possible and fish of the 1954 year class were recorded separately from those of older age groups.

Immature dipterans, primarily chironomids in the pupal stage, comprised the greatest proportion of the insect food. Chaoborinids were of lesser importance than the other midges and the utilization pattern suggests that they were scarce during August. Ceratopogonids formed a significant part of crappie food during the early season. Cladocerans and amphipods were the only other important invertebrates in the summer diet. The number of fish per stomach increased as the season advanced. In June crappies ate some perch from the 1953 year class, but later in the season used young-of-the-year fish. While many fish were hatched in June, they were not large enough to be used extensively for food until mid-July. It appeared that fish about 1 inch in length were the minimum size selected by crappies.

When the percentages of total volume formed by vertebrate and invertebrate food items per stomach were combined by 15-day intervals (Table 12), fish varied from a minimum of 18 percent in late June to a high of 70 percent in early October. While there was considerable variation in food composition following the June low, fish became increasingly important as the season progressed. Fish occurred more frequently in large than in small crappies and the food of some of the largest individuals consisted entirely of fish.

TABLE 12.—*Fish and invertebrates in the diet of catchable-size crappies in Linwood Lake in the 1954 summer season, expressed as percentage of total volume per stomach*

Date	Number of stomachs	Invertebrates	Fishes
June 1-15	18	35.5	64.5
June 16-30	18	82.0	18.0
July 1-15	27	63.2	36.8
July 16-31	29	35.4	64.6
August 1-15	8	51.0	49.0
August 16-31	5	64.0	36.0
September 1-15	5	44.2	55.8
September 16-30	16	40.0	60.0
October 1-15	16	30.0	70.0

Other workers have shown similar results with fish varying from 15 to more than 50

TABLE 11.—*The food of catchable-size crappies in Linwood Lake during the 1954 summer season, expressed as number and percentage of invertebrate animals and number of fish per stomach*

Item	June		July		August		September		October	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Total stomachs	33		56		13		21		16	
Empty stomachs	2		11		0		2		2	
Ephemeroptera	1.7	0.4	1.9	3.1	—	—	1.9	0.8	T[1]	T
Odonata	0.2	T	0.1	0.2	—	—	0.3	0.1	0.1	0.2
Hemiptera	0.3	0.1	0.3	0.5	—	—	—	—	—	—
Trichoptera	0.5	0.1	0.1	0.2	0.4	0.6	—	—	—	—
Coleoptera	—	—	0.2	0.3	0.1	0.2	—	—	—	—
Chironomidae	32.2	6.9	28.3	46.8	41.3	64.6	21.0	9.3	5.3	8.8
Chaoborinae	7.7	1.6	15.8	26.2	—	—	30.3	13.5	19.0	31.4
Ceratopogonidae	9.6	2.0	1.3	2.1	0.7	1.1	T	T	—	—
Cladocera	413.8	88.4	8.4	13.9	12.4	19.4	129.9	57.7	12.9	21.3
Hyalella	0.7	0.2	3.4	5.6	8.7	13.6	41.9	18.6	23.2	38.3
Hydracharina	1.4	0.3	0.5	0.8	—	—	T	T	—	—
Copepoda	—	—	0.2	0.3	0.3	0.5	T	T	—	—
Total	468.1	100.0	60.5	100.0	63.9	100.0	225.3	100.0	60.5	100.0
Minnows	0.2		0.4		0.1		—		—	
Sunfish (yy)[2]	—		0.1		0.4		0.4		0.4	
Perch (I-annulus)	0.1		—		—		—		—	
Perch (yy)	T		0.4		0.2		0.5		0.3	

[1] Trace.
[2] Young-of-the-year.

percent of total food volume (Pearse, 1919; Reid, 1950).

The condition factor of crappies, calculated in the manner described for bluegills, showed no definite seasonal changes.

The total variety of food items selected by crappies decreased as the season progressed, but there was a slight increase in numbers and kinds of organisms available. Utilization of fewer items coincided with increased use of chironomids, amphipods, and O-group fish. As in bluebills there was little relationship between apparent abundance of food items and their use (Tables 5 and 11). Selection of chironomids probably did not correspond to apparent abundance because more than half of the midges eaten were in pupal stages, which were free in the water and therefore unsampled. The increasing abundance of amphipods with advancing season coincided with an upswing in selection of these forms.

Selection of forage fish by crappies (Table 11) increased as the prey species became more available (Tables 6, 7, and 8). Since crappies seldom preyed on fish under 1 inch long, the young of some forage species were not eaten in significant quantities until late in the season.

A comparison of angler success with the food intake of crappies (Figure 5) during June, July, and early August showed that there was a reciprocal relationship between total food consumed and angler success. In late August and early September this relationship was not apparent but may have been obscured by small sample sizes. The negative relationship noted between rate of catch over the season and stomach fullness probably was caused to a large degree by the amount of fish in the diet.

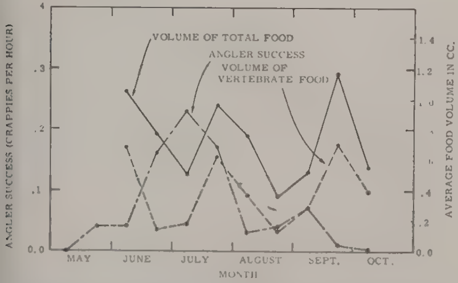

Figure 5.—The food volume per crappie stomach and the catch per angler-hour of this species in Linwood Lake during the 1954 season.

It has been shown earlier (Figure 3) that total angling success declined as vertebrate and invertebrate food animals became more abundant in the lake. This relationship existed also when the crappie catch was considered alone.

ANGLER CATCH IN RELATION TO PHYSICAL AND CHEMICAL FACTORS

In an effort to assess the immediate effects on fishing success of some of the more obvious physical and chemical conditions existing in Linwood Lake during the summer season, water temperature, turbidity, hydrogen-ion concentration, dissolved oxygen, carbon dioxide, and total carbonates were measured at approximately bi-weekly intervals and compared with creel census results.

Water temperature

Water temperature varied greatly during the fishing season and in midsummer rose to a maximum of 78° F. at the surface. In May the water was nearly isothermal from surface to bottom. A sharply defined thermocline was established about the middle of June and by early July it was located between the 20- and 25-foot levels. By mid-September thermal stratification had disappeared.

A comparison of seasonal changes in temperature with changes in angler success showed fishing success was poorer following the increase in water temperature and thermocline formation. Fishing failed to improve significantly in September, however, after the water had cooled. While temperature may indirectly affect angling success through its effect on food intake or food availability, the present study did not show that it directly influenced rate of catch.

Turbidity

When turbidity from algal blooms in late summer was highest, angling success was poor. This relationship was not consistent throughout the season, however, and no direct effect was clearly demonstrated.

Chemical factors

Measurements of dissolved carbonates, carbon dioxide, oxygen, and hydrogen-ion concentration were made at different levels in Linwood Lake on 11 dates in the 1954 summer season. There was no apparent direct relationship between any of these factors and angler success.

CONCLUSIONS

Current management of lake sport fisheries usually assumes that availability of fish to the fisherman remains constant throughout the angling season but creel-census records show that angler success varies widely during the course of a season with the catch generally being highest early in the summer and decreasing as the season progresses. Netting surveys indicate that during this period the abundance of catchable-size fishes varies little or is increased because rapid summer growth speeds recruitment into the fishery. The present investigation was undertaken in 1954 to explore possible causes of this catch pattern in Linwood Lake where survey information and creel-census data were available. Three principal game species, northern pike, black crappies, and bluegills, were included in the study.

A major part of the investigation was concerned with the relationship between angler success and the food of the fish. Estimates of food availability were obtained from analyses of bottom samples and seine catches, and food selectivity was determined from the examination of fish stomachs. A further objective was the determination of the effect of seasonal changes in physical and chemical conditions of the water on angler success. Measurements of water temperature, turbidity, hydrogen-ion concentration, dissolved oxygen, carbon dioxide, and total carbonates therefore were made periodically during the season and compared to catch rate.

Angling success in 1952, 1953, and 1954 was highest in June and early July and lowest in late summer. The rate of catch of northern pike, while never high, increased slightly in the fall of the 1954 season but catch of crappies and sunfish did not rise late in the season. In 1954 the abundance of invertebrate organisms was lowest in June and highest in September and early October. Numbers of young-of-the-year forage fish were greatest in July, but few of them were of a size selected by other fish for food until August. Following the July peak the total volume of young fish continued to increase although their numbers declined.

Angler success for pike was best when the percentage of stomachs containing food was lowest. In May, when the pike catch was relatively high, nearly half of the stomachs were empty. Later in the season when the catch was low, the proportion of empty stomachs dropped. No food other than fish was found in pike stomachs.

Stomach contents of sunfish and crappies indicated that these species were subsisting primarily on invertebrates during the period when angling success was at its peak. At this time abundance of available foods for these species was at the seasonal low.

The average volume of food in bluegill stomachs rose consistently from May through July and more than doubled during that period. Most of this increase was due to the ingestion of large quantities of rooted plant material after July 1. In July the rise in the amount of vegetation taken coincides with a sharp drop in the bluegill catch.

The volume of food in crappie stomachs varied considerably during the season but showed no definite trend. Changes in the total volume of fish ingested by crappies caused much of the variation. The invertebrate food intake, which consisted primarily of immature dipterans, remained more stable. There was some evidence of a reciprocal relationship between total ingested food and angler success in June, July, and early August. Since the change in the proportion of fish in stomach contents accounted for the rise in food volume, intake of fish was probably linked with angler success. In the early season of 1954 crappies were utilizing fish of the 1953 year class. Later, as young-of-the-year fish reached a suitable size, these were selected instead of older and larger fish.

Bluegills and crappies often failed to select items of food which sampling showed were most abundant. This discrepancy may be related to the differential availability of some items, such as burrowing forms, or inadequate sampling of some food items. At times it appeared that fish were selecting scarce food items which in reality were probably abundant.

The findings summarized above lead to several conclusions concerning causes of change in catch rate by anglers during the summer fishing season. Catch per unit of effort declines as the organisms eaten by fish become more abundant with advance in season. A rise in the average volume of food in bluegill and, to a lesser extent, in crappie stomachs coincides with increased abundance of available food. Changing food supply is therefore believed to bear a reciprocal relationship to changes in rate of catch and to be the principal factor causing seasonal fluctuations in angler success.

Physical and chemical factors exert little or no measurable influence upon angler success during the summer season except as they may influence food production.

ACKNOWLEDGMENTS

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INTERPRETATION OF VARICES AND GROWTH RIDGES ON SHELLS OF *EUPLEURA CAUDATA*

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INTERPRETATION OF VARICES AND GROWTH RIDGES ON SHELLS OF *EUPLEURA CAUDATA*[1]

In some bivalve mollusks, growth ridges are formed annually and can be used to determine age. For example, the Pismo clam (Weymouth 1923), the Pacific razor clam (Weymouth, McMillin and Holmes 1925), and the Pacific cockle (Weymouth and Thompson 1931) can be aged accurately by counting shell ridges. To my knowledge, only Magalhaes (1948), who found that from none to 3 growth ridges a year are formed on shells of *Busycon canaliculatum* and *B. carica* with no apparent relationship to age, and Clarke (1956), who states without experimental evidence that ridges on shells of *Nassarius trivittatus* probably have no relationship to age, have treated this subject with regard to snails. Cole (1942) attempted to assign ages to smooth oyster drills, *Urosalpinx cinerea,* by counting ridges on the siphonal canal, but he did not determine beforehand whether they were correlated with age. Andrews (1956) questioned Cole's conclusions on this account.

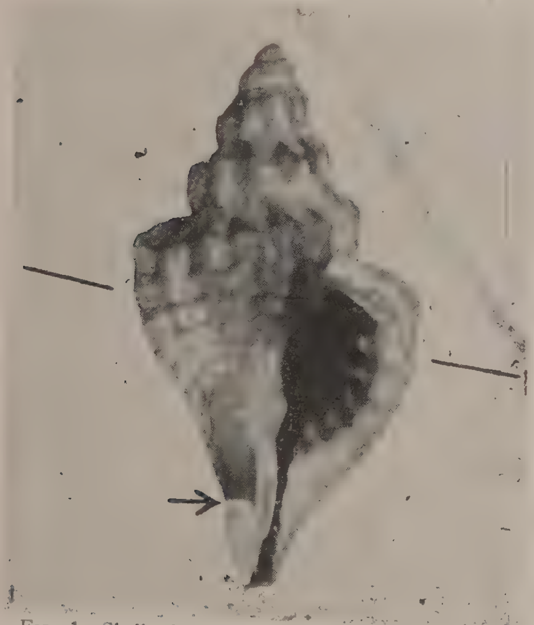

FIG. 1. Shell of *Eupleura caudata.* Arrow points to siphonal canal growth ridge. Lines at left and right show where shell was cut for Figure 2. Shell measures 22.0 mm in height.

It might be suspected that growth ridges on certain snails do not represent yearly markings because the distance between successive growth ridges is usually considerably smaller than yearly increments in growth. For example, recent observations at the Virginia Fisheries Laboratory of the rough oyster drill, *Eupleura caudata,* show that, whereas the distance from the siphonal growth ridge to the tip of a fully grown siphonal canal where the next growth ridge would appear may measure 2 to 6 mm, shell growth may exceed 10 mm a year (Figure 1).

Records of individual *E. caudata* actually showed that these snails do not deposit a consistent number of varices and siphonal canal ridges per growing season (Figures 1 and 2). Growth of this drill in Virginia waters extends from about the beginning of May to the end of October. In contrast to *U. cinera* which may have several or many small and usually poorly-defined growth ridges on its siphonal canal, *E. caudata* usually has one prominent ridge. When the first varix has been laid down, when the drill is 10 to 15 mm high, there is no ridge on the siphonal canal. After this, shell growth usually occurs as half-whorl increments. A thin layer of new shell material is deposited through an arc of 180° and then it flares out to form another varix. While this layer is being reinforced from the inside with successive layers of new shell, there is growth neither laterally at the varix margin nor longitudinally at the siphonal canal tip. It takes approximately 7 weeks to form and reinforce a half whorl. With its formation, a new growth ridge which consists of a line of demarcation between the tip of the old siphonal canal and the new shell appears on the new siphonal canal. Varices and growth ridges are formed with each successive half whorl of growth and old ridges are grown over.

In May 1956, 60 drills, having at least one varix and measuring in height from 12.8 to 26.2 mm, were caged and examined once a month until fall 1957, *i.e.* through 2 summers and a winter. The cages consisted of wooden frames with plastic screen sides and top (4 holes to a linear inch) and plastic screen bottoms (8 holes to a linear inch). The cages were 37 inches long, 16 inches wide and

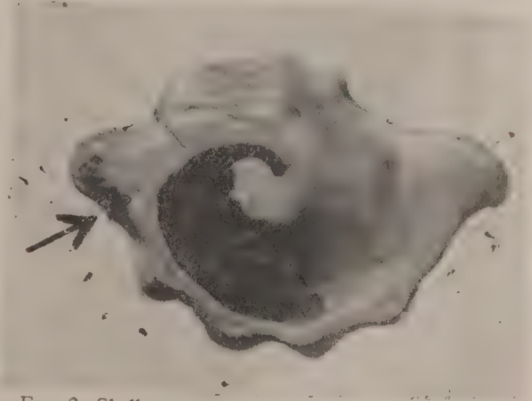

FIG. 2. Shell cut approximately perpendicular to longitudinal axis. Prominent ridges at left and right are varices. Four smaller ridges at bottom are axial ribs. Arrow points to place where growth of last half whorl of shell began. Shell grew in counterclockwise direction from here and stopped at varix on right.

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[1] Varices are prominent ridges parallel to the margin of the aperture on shells of certain snails. This research was conducted under a contract at the Virginia Fisheries Laboratory with the U. S. Fish and Wildlife Service, No. 14-19-008-2372, Study of Oyster Drills in Chesapeake Bay.

6 inches deep, and included 8 compartments 9 x 8 x 6 inches. For support and stability they were tied into seasoned, tarred sea-rac oyster trays (Hewatt and Andrews 1954) and suspended in the York River along the laboratory pier one foot from the bottom with from one to 3 feet of water covering them. A male and female drill were kept in each compartment with several one- and 2-year old oysters for food. Although ages of the drills were unknown, it is probable that both young and old drills were included in the experiment because their heights matched almost the full range of heights of hundreds of drills collected randomly from nature.

Most mature drills in cages did not grow either summer because growth of *E. caudata* usually ceases with the onset of sexual maturity (unpublished data). Mature females were considered as those which deposited embryo cases during the experiment. Immature females did not deposit cases. Mature males had a full-size penis. Growing drills did not form a consistent number of half whorls and coincident varices and siphonal growth ridges per growing season. Eight individuals each formed 2 in one summer, apparently a normal number because many wild drills collected in late summer near the cages also showed 2 half whorls which appeared to be newly formed. Seventeen caged drills deposited just one half whorl a summer, but only 2 of these grew during both summers. A single caged drill deposited 3 half whorls. Several drills died or were lost during the experimental period.

It is clear that varices and siphonal growth ridges on shells of *E. caudata* cannot be regarded as yearly formations and probably have little value in determining age of drills.

I wish to thank Dr. William J. Hargis, Jr. for guidance during this study, and Dr. J. D. Andrews for critically reading this paper.

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F 37

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DONALD F. MAIRS and CARL J. SINDERMANN, U. S. Bureau of Commerical Fisheries. Intraspecies variability in electrophoretic patterns of fish serum.

In 1958, Sindermann and Mairs (Anat. Rec., *30:* 1005) reported on the electrophoretic properties of sea herring (*Clupea harengus*) blood serum, giving the pattern apparently typical of the species and the effects of acute fungus infection upon that pattern. Since then, an effort has been made to assess the possible usefulness of paper electrophoresis in differentiating herring stocks. Nearly 300 patterns have been studied, including fish from spring- and fall-spawning aggregations in the Gulf of Saint Lawrence, fall spawners from Nova Scotia, spent and recovering adults from Georges Bank in the Gulf of Maine, and immature "sardine-size" herring from the Maine coast.

Wide variability in patterns is evident within the species. The most frequent exception to the three-peak pattern typical of the adults reported in 1958 is a splitting of the lead anodal fraction into two separate peaks; this occurs in 95% of the immature (one to three-year-old) fish, and in varying but much lower numbers in the different adult aggregations. Another exception was found in the occasional separation into two definite components of the second fraction of the typical pattern. This occurred in all the populations sampled, in small and differing amounts. The least mobile peak was infrequently divided; in a few fish this fraction was so weak as to be barely noticeable. The Georges Bank adults displayed two abnormalities seen in no other group, i.e., complete absence of the second peak in a few fish, and a division of the lead peak into three distinct fractions in 14 of the 44 fish examined from that area; these two variants were the only consistent differences which offered hope of electrophoretic characterization in any of the populations sampled.

The suggestion has been made (Moore, '45; Dessauer and Fox, '56) that age may affect electrophoresis patterns. The splitting of the lead fraction in immature fish is significantly higher at the 1 per cent level by chi-square analysis than in any of the adult populations; this suggests the definite possibility that the effect could be age-relative, although other factors may well be operating. In view of the intraspecies variability disclosed by this study, it seems inadvisable to assume absolute specificity of electrophoresis patterns in closely related groups unless considerable numbers of individuals have been examined.

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3. CAUSES OF MAJOR VARIATIONS IN THE CATCH OF THE PACIFIC SARDINE, *Sardinops caerulea* (GIRARD)[1]

From its position as one of the world's largest fisheries, the Pacific sardine fishery decreased by an order of magnitude in both area and landings.

This decline cannot be shown, directly or indirectly, to be attributable to the fishery. Rather, the decline was probably associated with the effects of the environment upon year-class size.

A model which is consonant with the features of sardine biology and the fishery and which offers an explanation of the decline is:

1. Sardines which support the United States and Canadian catch are produced off southern California and central Baja California;

2. those produced off southern California migrate as far north as British Columbia, support the fishery there, and contribute to the fisheries at San Francisco, Monterey, and San Pedro;

3. those produced off central Baja California migrate as far north as central California and contribute to the California fisheries, especially at San Pedro;

4. lack of spawning success on the southern California spawning grounds since about 1943 could account for the observed changes in the fishery;

5. the postulated lack of spawning success off southern California is attributed to the below average temperature regime, which has delayed spawning by one or two months;

6. below average temperatures are associated with an upwelling regime and above average temperature with an advection regime;

7. under the upwelling regime, it is suggested that the sardine is unable to compete successfully with the anchovy.

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Notes on the Hawaiian Frigate Mackerel of the Genus *Auxis*

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April, 1960

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Notes on the Hawaiian Frigate Mackerel of the Genus *Auxis*

WALTER M. MATSUMOTO[1]

A NEW DISTRIBUTION RECORD for a long-corseletted frigate mackerel of the genus *Auxis* was established on November 30, 1957, with the capture of 21 specimens in the central Pacific Ocean. These fish were taken from the same school together with five short-corseletted frigate mackerels. The catch was made from the research vessel "John R. Manning" of the Pacific Oceanic Fishery Investigations (POFI), by pole-and-line fishing, one mile offshore, two miles northwest of Cape Kaea, Lanai. Although the long- and short-corseletted *Auxis* are known from both sides of the Pacific, only the short-corseletted form has been reported heretofore from the central Pacific area.

As is the case with some of the other scombrids, the taxonomy of this genus is not very clear. Although the identity of the short-corseletted form has been well established as *A. thazard* (Lacépède 1802), the nomenclature of the long-corseletted form has been confused because of incomplete description and subsequent misnaming by other workers. It is hoped that this paper will help to clarify the nomenclature of this genus.

The long-corseletted form of the western Pacific has been identified by various names. Kishinouye (1915: 13–14) recognized two species of *Auxis* in Japanese waters, to which he ascribed the names *A. hira* and *A. maru.* The former species was described as having a short corselet which ended slightly posterior to the pectoral fin, whereas the latter was described as having a long corselet which extended to the anal fin. Under the description of the latter species, Kishinouye stated that "Bleeker's *tapeinosoma* may also be this species, but the figure and description of this species are very rough and unclear." In recent years Herre and Herald (1951: 319) and Wade (1949: 229) applied the name *tapeinosoma* to the Philippine long-corseletted form. A review of Bleeker's original description (1854: 408), however, discloses that *tapeinosoma* is definitely a short-corseletted form, for according to him the corselet ends "slightly posterior to the pectoral fins." This character agrees with the short corselet of *thazard* and *hira,* and therefore, *tapeinosoma,* as used by Herre and Herald, and by Wade, in identifying the long-corseletted species is a misnomer.

The appropriate name for the western Pacific long-corseletted species seems to be *A. thynnoides* Bleeker. Examination of Bleeker's (1855: 301) original description of the type specimen which was taken at Ternate, East Indies, and which is now in the Leiden Museum, clearly indicates that his specimen is the long-corseletted form, for he states that the corselet along the lateral line ends "far behind the pectoral fin." The writer's interpretation of Bleeker's description is confirmed by John E. Fitch (through private correspondence), who has checked the type specimen. It is apparent from the original description and from Fitch's information that *thynnoides* is the earliest available name for the western Pacific long-corseletted species. The Hawaiian form described here is identical with that from the Philippine waters and agrees well with the type specimen described by Bleeker. Consequently, it is given the name *A. thynnoides* Bleeker.

A. thazard has been described many times by previous workers. Nevertheless, in order to facilitate the comparison between this species and *thynnoides,* the descriptions of both are presented.

DESCRIPTIONS OF SPECIES

Auxis thynnoides Bleeker

Fig. 1

This description is based on 20 specimens which are now deposited at the POFI laboratory, Honolulu, Hawaii.

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[1] Fishery Research Biologist, Bureau of Commercial Fisheries, Hawaii Area, Honolulu. Manuscript received September 17, 1958.

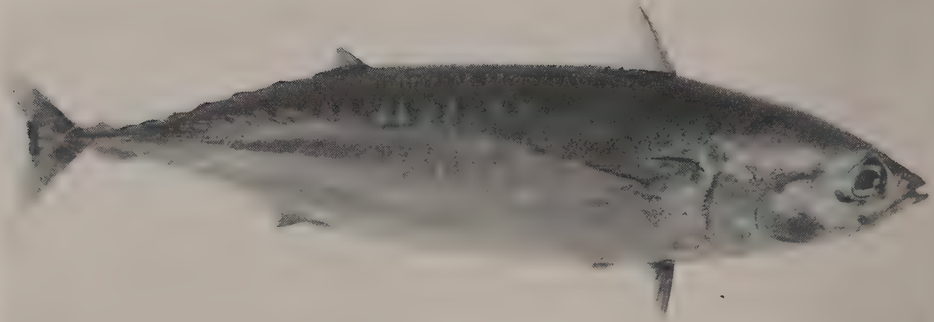

FIG. 1. *Auxis thynnoides* Bleeker.

Dorsal X–XI, 10–11, 8. Anal 12–13, 7. Gill rakers 10–11 + 1 + 32–36 = 43–48. Total length 262–290 mm.

Body robust, fusiform, almost cylindrical in cross section. Snout short, pointed. Mouth moderate; gape to slightly past anterior margin of pupil. Each jaw with single row of small, weak teeth. Palatines and vomer toothless. Dorsal fins well separated. Dorsal interspace slightly greater than half the distance between origins of first and second dorsals.

Vertebrae 20 + 19 = 39, including urostyle. First haemal arch on 8th vertebra; first closed haemal arch and first haemal spine on 21st vertebra. Haemal canal borne away from body of vertebra by pedicles [of Starks (1910: 97) = epihaemal processes of Kishinouye (1923: 460)].

Body naked, except for corselet of scales. Corselet along lateral line extends beyond vertical through posterior end of second dorsal. Corselet 16–18 scale-rows wide below origin of second dorsal fin. Lateral line more or less undulating, without any pronounced arch.

Body markings consist of 14–16 dark, nearly vertical bars over bluish background above lateral line. Bars often broken into spots. Dark continuous band over top of head and along dorsal margin of body. The band more or less uniform in width to end of second dorsal, whence it narrows posteriorly to base of caudal fin. Body below lateral line silvery white and free of markings or spots.

Auxis thazard (Lacépède)
Fig. 2

This description is based on five specimens which are deposited at the POFI laboratory, Honolulu, Hawaii.

Dorsal XI, 10–12, 8. Anal 13, 7. Gill rakers 9–10 + 1 + 28–31 = 39–42. Total length 272–283 mm.

Body robust, more or less compressed laterally. Snout short, pointed. Mouth moderate; gape to well past anterior edge of pupil. Each jaw with single row of small, weak teeth. Palatines and vomer toothless. Dorsal fins well separated. Dorsal interspace less than half the distance between the origins of the first and second dorsals.

Vertebrae 20 + 19 = 39, including urostyle. First haemal arch on 8th vertebra; first closed haemal arch and first haemal spine on 21st vertebra. Haemal canal borne away from body of vertebra by pedicles.

Body naked, except for corselet of scales. Corselet along lateral line extends posteriorly to about two-thirds the distance from the origin of first dorsal to the origin of second dorsal. Lateral line only one or two scale-rows wide beneath second dorsal origin. Lateral line more or less undulating, without any pronounced arch.

Body markings about 16 dark, oblique bars running posterodorsally and overlying bluish background above lateral line. Bars variable in number and often broken into spots. Dark continuous band over top of head and along dorsal margin of body. The band more or less uniform in width to above tip of pectorals whence it narrows posteriorly to base of second dorsal finlet. Body below lateral line silvery white and free of markings or spots.

DISCUSSION

Several distinguishing characters are noted in the two types of *Auxis* described here. The most obvious of these is the corselet formation along the lateral line. In *thazard* the corselet narrows abruptly toward the lateral line and ends at about two-thirds of the distance from the origin of the first dorsal to the origin of the second dorsal fin. On larger specimens, 350 to 400 mm. long, according to Wade (1949: 234), the corselet tapers less rapidly than in smaller specimens, but in no case does it extend to the level of the second dorsal origin. In contrast to this the corselet of *thynnoides* tapers very gradually and terminates between the first and second dorsal finlet. In the Hawaiian specimens the corselet is still 16 to 18 scale-rows wide beneath the origin of the second dorsal fin. In the smaller Philippine specimens, whose total lengths range between 195 and 235 mm., the corselet beneath the second dorsal fin is from 9 to 15 scale-rows wide.

Upon examining the corselet of these specimens, it was noticed that the largest scales were adjacent to the lateral line, and that the size of the scales diminished on each succeeding scale-row away from the lateral line. From this observation and also from the previous one, that the larger Hawaiian specimens have more scale-rows than the smaller Philippine specimens, it was suspected that the width of the corselet increased with growth of the fish. An analysis of the regression of number of scale-rows on fish length (Hawaiian and Philippine material combined) yielded the equation, $Y = 0.078 \times - 4.55$, which is shown graphically in Figure 3. The highly significant regression coefficient ($b = 0.078$; $t = 12.14$, $P < 0.001$, at 19 degrees of freedom) indicates that the number of scale-rows increases as the body length does, and that therefore, the variation in corselet width between the Philippine and Hawaiian specimens represents growth rather than a species difference.

An interesting character, one which has seldom been used previously in separating the two forms of *Auxis,* is the configuration of body markings. In both species the dorsal half of the body contains a number of dark bars. Although these bars vary in number and are sometimes broken into spots, their position on the body is distinctive. In *thazard* the bars lie obliquely in a posterodorsal direction. In addition to these bars, the dorsal surface of the body is marked with a dark longitudinal band which is as wide as the interorbital space and which extends evenly from the snout to above the tip of the pectoral fin. It then tapers gradually to about the base of the second dorsal finlet. In *thynnoides,* on the other hand, the bars lie in a more

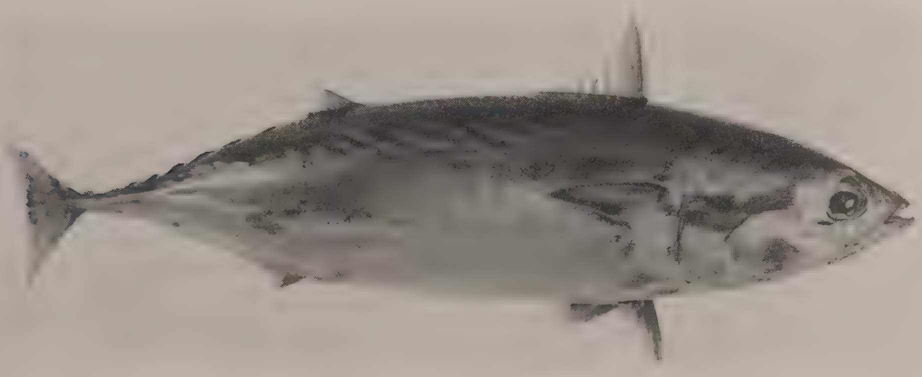

FIG. 2. *Auxis thazard* (Lacépède).

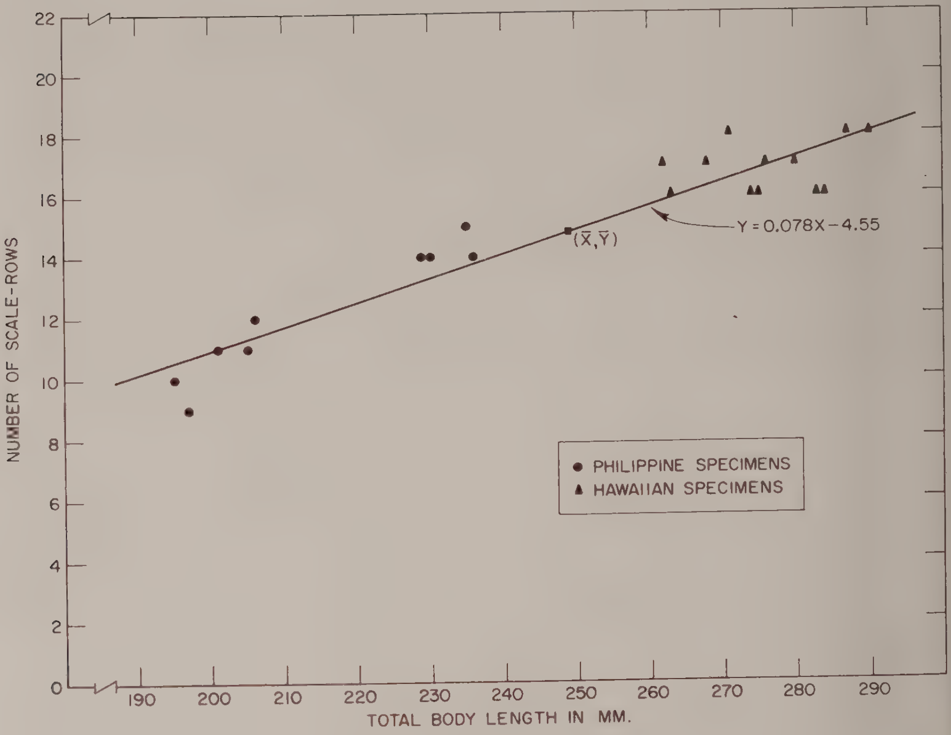

FIG. 3. Regression of the number of scale-rows on total body length of *Auxis thynnoides.*

or less vertical direction, and the dark longitudinal band on the dorsal surface of the body does not taper noticeably until it reaches the end of the second dorsal fin, whence it continues to the base of the caudal fin, tapering very gradually.

Another character often mentioned by investigators in separating the two forms of *Auxis* is the difference in the roundness of the body. In both species the ratios of body length (fork length) to body width are nearly identical (6.04 to 6.56 in *thazard;* 6.02 to 6.58 in *thynnoides);* however, the ratio of body length to body depth of *thynnoides* (4.55 to 4.98) is greater than that of *thazard* (4.32 to 4.56). Consequently, *thynnoides* appears fusiform, whereas *thazard,* because of its greater depth, appears laterally compressed. In visual comparison, this difference is so slight that it requires an unusually keen observer or one who has had practice in this observation to notice the difference.

Nearly all of the characters examined on the two species exhibit very small differences which are difficult to recognize in the field. Even the relatively more obvious corselet difference would elude detection unless the observer was looking for it specifically. This being the case, the question arises as to whether *thynnoides* was present in these waters previous to this capture but was undetected, or whether its recent capture indicates a movement of this fish into the area.

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STABILIZATION OF THE CARBOHYDRATE CONTENT OF SEA WATER SAMPLES

It is the practice during many oceanographic investigations to analyze sea water samples immediately after collection. This has been necessary due to difficulties involved in stabilizing a sample during storage. Collier and Marvin (1953) have demonstrated that the inorganic to organic phosphorus ratio of a sea water sample can be effectively stabilized for long periods of time by freezing. The purpose of this experiment was to determine if carbohydrate materials (see Collier, *et al.* 1953) could be similarly stabilized.

A sea water medium that contained a bacterized culture of the organism *Prorocentrum* sp. was chosen because such a medium is relatively rich in dissolved organic material. A portion of the medium was first centrifuged through a Sharples centrifuge to remove as many organisms as possible and was then thoroughly mixed. Fifty-ml portions were then dispensed into clean 25 × 200 mm culture vials and capped with solid polyethylene screw caps. All cap-glass junctions were sealed with plastic insulating tape. Of the 130 vials filled, half were frozen and stored at minus 18°C and half were stored at room temperature. Groups of 8 vials were taken from both the frozen and unfrozen material at the intervals indicated in Figure 1. Employing the method of Zein-Eldin and May (1958), four measurements of the carbohydrate content of each sample were made, making a total of 32 determinations per time interval.

Immediately prior to storage, the carbohydrate concentration in the centrifuged sea water medium was estimated at 3.8 ±

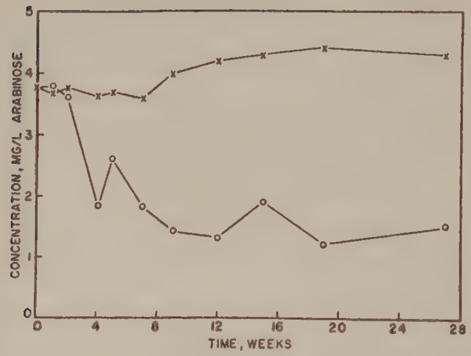

FIG. 1. Carbohydrate content of sample plotted against storage time of sample. The two plots x—x—x and 0—0—0 indicate mean values of 8 frozen and unfrozen samples respectively at each time interval.

TABLE 1. *Standard error of means of each frozen group*

Group	Elapsed time Weeks	Mean (mg/L)	Standard error (mg/L)
1	1	3.70	0.096
2	2	3.80	0.082
3	4	3.65	0.047
4	5	3.70	0.043
5	7	3.65	0.057
6	9	4.0	0.032
7	12	4.2	0.038
8	15	4.3	0.030
9	19	4.4	0.078
10	27	4.3	0.083

0.1 mg/L arabinose equivalents. Subsequent estimates from the frozen and unfrozen material are plotted against time in Figure 1. Estimates from the frozen material did not vary more than ± 0.15 mg/L for a period of 7 weeks. In contrast, carbohydrate concentration in the material not frozen generally diminished as length of storage time increased. The somewhat erratic values obtained in the medium not frozen might be expected since biotic activity within different vials undoubtedly proceeds at different rates.

Comparison of the two curves shows that freezing stabilizes the carbohydrate content of sea water for periods up to 7 weeks. Since the average deviation within groups of frozen samples was less than 0.1 mg/L at any one period (Table 1), a reasonable assumption is that the increase in mean values after the 7th week was not due to sampling variation, but rather to unknown factors. For example, bacteria or fungi not eliminated during the process of centrifugation could have survived the freezing temperatures. The growth of these organisms might have caused the increase of arabinose equivalents.

This supposition suggests that further investigation should be conducted on the biological activities of micro-organisms at freezing temperatures and during the time lapse between thawing and analysis of samples.

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3. IGY OCEANOGRAPHIC PROGRAM AND THE DEVELOPMENT CONCERNING THE PACIFIC EQUATORIAL UNDERCURRENT[1]

Most of the commitments and plans for oceanographic research in the Pacific submitted at preliminary IGY meetings were completed. The most intensive coverage was in the coastal areas off North America and Asia. There were no quasi-synoptic surveys such as the 1955 NORPAC[2] and 1956 EQUAPAC[3] surveys. Two important strictly IGY projects were the studies to obtain data on the age and rate of replacement of the deep and bottom waters and studies of the circulation and mass transport in the eastern equatorial Pacific.

The deep circulation studies consisted of direct current measurements from the Russian "R/V Vitiaz" at numerous stations around the entire North Pacific and deep water sampling in the eastern Pacific from vessels of Canada's Pacific Oceanographic Group from Nanaimo, B. C., the University of Washington, and Scripps Institution of Oceanography. The sampling program extended from 50°N. to 45°S. latitude.

The studies of the circulation and mass transport in the eastern equatorial Pacific consisted of two multiple ship surveys. One was the study of the Equatorial Countercurrent (Doldrum Expedition) by Scripps Institution of Oceanography and the Colombian Navy and the other was the study of the Pacific Equatorial Undercurrent (Cromwell Current) by Scripps Institution of Oceanography and the Honolulu Biological Laboratory.

The Countercurrent Survey disclosed an average transport of 60 million cubic meters per second, which was two to three times that computed from previous observations. The reason for the increase was the transport between 200 and 800 meters which was revealed by direct measurement of the currents[4].

The Pacific Equatorial Undercurrent (Cromwell Current) survey yielded an estimate of its volume transport and eastern limit. It was found to extend from at least 140°W. to 92°W. longitude and to be completely embedded beneath the surface in the westerly flowing South Equatorial Current. The core of the current was centered on the equator where velocities of 2–3½ knots occurred between 140°W. and 95°W. On 140°W. the current occurred between 30 and 300 meters with the maximum velocities occurring at about 100 meters. It was symmetrical about the equator; thinning and weakening to the north and south so that at 2°N. and 2°S. it was only 30 m. thick and had maximum velocities of only 0.6 knots. The average transport of current on 140°W. was 30 million cubic meters per second or more than that previously given for the Equatorial Countercurrent itself[5].

The importance of the undercurrent studies were that they showed a need for reconsideration of the water balance in the equatorial Pacific and perhaps other areas as well in order to determine the role submerged currents play in the water balance of the oceans and transport of pelagic organisms.

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[1] Published by permission of the Director, U. S. Bureau of Commercial Fisheries.

[2] NORPAC was a multiship survey of the Pacific Ocean north of 20°N. latitude during July–September 1955 by vessels of Canada, Japan, and the United States.

[3] EQUAPAC was a multiship survey of the equatorial Pacific Ocean, 20°N. to 20°S. latitude and west of 130°W. longitude, during August–September 1956 by vessels of France, Japan, and the United States.

[4] J. A. Knauss and R. Pepin, Nature 183: 380 (1959).

[5] J. A. Knauss and J. E. King, Nature 182: 601-602 (1958).

PERUVIAN ANCHOVY

THE WORLD'S LARGEST FISHERY

F#2

By J. L. McHUGH*

The giant Peruvian anchovy fishery has doubled its catch yearly since the first reduction plant was put into operation in 1950. Last year nearly two million tons were landed—almost twice the U.S. menhaden catch. This phenomenal catch produced 300,000 tons of fish meal and 19,000 tons of oil—most of which was exported.

AMONG the difficulties facing the menhaden industry today, a serious one has been the rapid growth of the Peruvian anchovy fishery. What are the conditions that allow such a phenomenal catch from one small country and what is the potential of this, the world's largest industrial fishery? The answers to these questions should be of considerable interest to our own menhaden industry.

The Peruvian coastline lies just south of the equator, extending from about 3° to 19° South Latitude. Thus, it is about as long as the Pacific coasts of Washington, Oregon, and California combined. Despite this tropical location, however, the coastal climate is relatively mild, with a mean annual temperature of 70° F. and a range from 55° to 90°. From the Andes to the Coast, the land has no lush cover of tropical vegetation, for it seldom rains, and this coastal band is a parched and barren desert, except where crops have been stimulated to grow by irrigation from the coastal streams.

Here is a strange paradox—a temperate climate in a tropical land, a coastal desert adjoining an ocean teeming with life, perhaps one of the richest fishing grounds in the sea.

Perhaps the best-known fact about Peru has been its fame as the home of the guano islands, where deposits of nitrogen-rich fertilizer, hundreds of feet thick, have been mined for many years.

Until recently this was one of Peru's leading industries, and certainly the best-known. The sparse rainfall, which is even scantier on the islands off the coast, has been a major cause of these vast accumulations of guano, for otherwise the nitrogen that assures the high quality of this natural fertilizer would have been converted to ammonia and lost to the atmosphere, even if the rains did not wash the deposits into the sea as fast as they accumulated.

This striking lack of rainfall, so essential for accumulation of guano, is caused by the very conditions that make the adjacent ocean so rich in marine life. The abundant stocks of fish are equally important to the guano industry, for without them the vast flocks of birds that produce the guano would not be able to survive.

The essential basic conditions, which exist simultaneously nowhere else in the world in quite such perfect balance are a wind system that drives the warm surface waters away from the coast, to be replaced by cool, nutrient-rich water from below; a narrow continental shelf, which brings the deep, rich waters close to shore, and birds of a kind that spend most of their time on shore when they are not feeding, so that their droppings fall on the land.

The cool ocean waters cool the air that moves over the coastal region of Peru and temper the coastal climate. Cool air does not hold as much moisture as warm air; and as it moves in over the land it becomes warmer, its capacity to hold moisture increases, and condensation as rain is impossible. Thus, the land is a desert.

The incredible richness of the living resources of the sea in this region has been poorly understood until now, for despite the importance of the guano industry, and the catastrophes that occur when El Nino (strange meteorological phenomena) visits the coast, no permanent scientific investigations have been organized until very recently.

There was even disagreement as to which animals were chiefly responsible for the deposits, for at least eight different groups of marine birds, several varieties of shore birds, and sea lions, are numerous in the area.

Estimates of the abundance of anchovies have been made by ingenious methods. These begin with estimates of the abundance of birds, which can be derived from direct counts, or from food intake and known rates of accumulation of guano on the islands. The amount of nitrogen in the bodies of anchovies can be determined by chemical analysis, and from this can be obtained an estimate of the numbers of anchovies required to produce given amounts of guano. From these calculations it has been estimated that the guano birds consume more than five million tons of anchovies each year. Obviously, the birds do not consume all the anchovies in the ocean, hence this is a minimum estimate of the total numbers of anchovies present.

(Continued on Page 60)

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*Division of Biological Research, U.S. Bureau of Commercial Fisheries. From a talk presented at the Annual Meeting of the Menhaden Fishery Processors, Virginia Fishermen's Association, Old Point Comfort, Virginia, February 9, 1960.

PERUVIAN ANCHOVY

(Continued from Page 35)

The comorants, because they nest close together and on level ground, and are extremely abundant, are considered to be the chief producers of guano. Other birds, less gregarious, less inclined to stay on shore, or inclined to roost on cliffs, may not contribute so greatly to the accumulation of guano, although they may consume large quantities of fish. Therefore, the true abundance of anchovies may be several times greater than the estimates given above. It is obvious that the potential of the new commercial fishery for anchovies is not yet fully realized.

One of the most universal characteristics of the fisheries is their fluctuations, and it is important to consider what effects such phenomena may have upon the Peruvian anchovy fishery, and the economic threat that it offers to the menhaden industry. The phenomena El Nino and the Callao Painter, bring high temperatures, rains, and mass mortalities of marine life to the Peruvian coast, and kill birds by starvation or drive them away from their usual haunts.

Because scientific investigation has received little attention in this important fishing region, we do not know too well what effects these strange phenomena have. But what we do know leads us to believe that a commercial fishery for anchovies should be more profitable, on the average, than the system of using birds as fertilizer factories.

Comparing the two methods directly, we are not sure which is most efficient—birds absorb energy in the form of the food they eat—they use much of it for flight, body metabolism, reproduction, and the like. What is left is discarded as guano.

A fishery, on the other hand, also is inefficient—it spends money to build boats, operate them, provide food, lodging, and pay for fishermen, power to operate reduction plants, and the like. No one has calculated the relative efficiency of birds vs. man. But the inefficiency of birds as fish-meal factories is not well understood. We have cited already such things as scattered distribution of drippings, loss to the sea, and so on.

Recent discoveries raise other questions that may be important. El Nino is caused by a change in meteorological conditions that change the direction of prevailing winds, prevent upwelling of nutrient-rich waters from the deeps, and cause the temperatuer of Peruvian coastal waters to rise. This kills vast quantities of marine life, the decomposition of which produces hydrogen sulphide, the cause of the Callao Painter; and causes the death or migration of millions of birds.

Our latest information, however, tells us that the anchovies are not seriously affected, because they can drop below the critical zone and continue to feed and grow with little difficulty. They are still available to the commercial fishery in about the same numbers as before, hence the change in currents may be of little consequence to fishermen.

Thus, an anchovy fishery may be much more productive than the guano industry. The last three years have been El Nino years—the worst since 1925—and it has been estimated that only ten million of the original 30 million cormorants have survived. Thus, the present fishery is taking just about exactly what the missing 20 million birds once ate. An intensive fishery could prevent the bird population from building up again, and perhaps could cause it to decline even farther. Who knows what the potential of this fantastic fishery may be?

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COMMENTS ON COMMON NAMES OF FISHES

KEY TO THE NAMES OF BRITISH FISHES, MAMMALS, AMPHIBIANS AND REPTILES, by R. D. Macloed, Pitman & Sons, London, 1956, 71 pp. (—/12/6); and A LIST OF COMMON AND SCIENTIFIC NAMES OF FISHES FROM THE UNITED STATES AND CANADA (second edition), by a joint committee of the American Fisheries Society and the American Society of Ichthyologists and Herpetologists, American Fisheries Society Special Publ. no. 2, 102 pp., 1960 ($1.00 in paper, $2.00 in cloth; available from E. A. Seaman, Box 483, McLean, Virginia).—These two works are accounts of the common and scientific names applied to certain of the vertebrate animals of Great Britain, and of the United States and Canada respectively. Each includes an account of the names of fishes (and the reviewers must restrict their comments on Macloed's volume to the sections on fishes) and each represents a considerable effort, but here the similarity ends. These two volumes were written by different authors for different purposes; thus the differences in content and presentation are not astonishing. But to the reviewers, these differences reflect also those between scholarship and expediency, interest in a problem and fulfillment of a duty, and understanding of the inherent attributes of the common name and lack of such appreciation.

The first of these two publications has only recently come to the notice of the reviewers, but it is felt that a belated review of this contribution is better than none, as its approach to the problem of common names is so different from that of the American Fisheries Society.

Macloed begins his book with a 14-page introduction in which he discusses, among other things, the purpose and plan of his book, a bit about the origin and derivation of scientific names, and statements on the classification, form and origin of common names. "List I: Scientific Names" begins on page 19. Some 206 generic names are entered alphabetically in the section devoted to fishes, each entry being followed by the name of the author, a brief comment on the derivation of the entry, and some notice of the species and a comment on the specific name or names included under the genus. A total of 360 specific or subspecific names are so treated in the list. All scientific names are given in bold-face for ease of reference.

"List II: Common Names" begins on page 53, and the fish section contains 261 alphabetically arranged entries in bold-face, most of which are followed by the scientific name in italics and a comment as to the derivation. This section is extensively cross-referenced, and in those entries which lack a scientific name, reference is given to another entry. Subentries are given under many of the major entries.

Macloed has combined philological and zoological evidence into an entertaining and well-documented synopsis of the origin and derivation of common and scientific names. He has not prescribed names; he has not tried to arbitrate among competing names, and he has not invented names. He has very simply told us what names now exist and how they came to be; for example:

"**Lamna** Cuvier. Gr. *lamna*, large shark (Oppian: *Halieutika* I, 370). **L. cornubica** (Gmelin), porbeagle. 'Cornish'; coined word with form of L. fem. adj.; not common round Cornwall, though it has been found there and *porbeagle* is a Cornish name." (Macloed, p. 28)

"**Porbeagle,** *Lamna cornubica*. Said to be a Cornish name, compounded of Fr. *porc*, pig, and E. *beagle; porc*, from this shark's gross appearance; *beagle*, from its habit of hunting in 'packs,' cf. *dogfish*." (Macloed, p. 61)

By analyzing common names as they exist, the author has contributed to all of those to whom true common names are appropriately of concern: students of history, anthropology and philology as well as zoology. Our thanks, belatedly, to R. D. Macloed for this most welcome and enjoyable contribution!

The second of the two works is prefaced by a legalistic introduction, the list itself being presented in a generally accepted phylogenetic sequence. Scientific family names are given a common name designation; and within each family the scientific names are listed alphabetically, each with its author, common name and a letter designating Atlantic, Pacific, or Fresh Water, for example:

"Porbeagle A *Lamna nasus* (Bonaterre)" (p. 7)

Part II is an alphabetical index to common names, and includes some widely-used names not "accepted" by the Committee. Part III is an alphabetical index to scientific names.

The reader may be aware that we are approaching the American effort in a somewhat critical sense, and such being the case it behooves us to outline our points of disagreement. The crux of the disparity in the philosophical approach to the problem of common names lies in the definitions of the term common name. The American Committee gives us the following:

"The common name as here employed is viewed as a formal, usually anglicized appellaon to be used in lieu of the Latinized scientific me of a species." (p. 1)

We submit that this is an uncritical and super- ial use of the term and that whatever its intent, e Committee is "playing with fire". Macloed, contrast, has considered the matter in a more oughtful vein and has provided the following:

"Common names may be divided into three ain classes according to their origin and the ecision of their application, though no hard d fast line can be drawn between them. At one d are book-names, that is to say, names that ave been invented by naturalists and, generally eaking, are used only by those who take their ology seriously. These names are naturally uite precise and refer definitely to one particu- r species or subspecies. At the other extreme e popular names, that is to say, colloquial ames that have grown up spontaneously among rdinary people. Their form and currency are sually both local. As we have already seen, such ames have an elastic application and are often sed indiscriminately for several kinds of fish or nimal. Between these precise book-names and hese loose popular names there lies the third lass that we may call the ordinary common ames. These, like popular names, have grown p spontaneously, but, unlike popular names, re part of the national language and are in ation-wide use. They are, as a rule, definite nough in a generic kind of way, but often too eneral to denote one species in particular. To vercome this difficulty, such names are often onverted into book-names by the prefixing of ome distinctive epithet. Thus *Hare* and *Pipe-fish* ave been used to form the book-names *Irish are* and *Broad-nosed pipe-fish*." (Macloed, p. 13)

In their excessively legalistic devotion to self- mposed rules and restrictions, the American Committee has failed to appreciate the fact, im- plicit in Macloed's discussion of what a common ame is, that the term is itself generic in scope. By being, in their definition of common name, umpers when they should have been splitters, he members of the American Committee have aken a difficult semantic problem, the magni- ude of which they apparently failed to grasp, and left it far worse than when they started. The act of attempting to create popular names (Mac- oed's definition) is doomed to failure, and an only discredit the very necessary functions his Committee should fulfill: that of establishing uniform book names (Macloed's definition) *when the need for such names is clearly mandatory*, and with the full realization that these are book names and nothing more.

Now another objection to the American Com- mittee is their autocratic approach to the problem of common names. This, of course, is a corollary of their failure to comprehend the implications of the term "common name"; nonetheless, when Macloed, when Osorio de Castro (Glossário de Nomes dos Peixes, Gabinete de Estudos das Pescas, Publ. no. 20, Lisboa, 1954), and when the International Council for the Exploration of the Sea (Catalogue des poissons du Nord de l'Europe, Avec les Noms Vulgaires Dont On Se Sert Dans Les Langues de Cette Région, Publ. Circonstance, no. 12, Copenhagen, 1914), among others, report to us what common names *are* used and the American Committee tells us what names they have *accepted* for us to use, we cannot feel otherwise than outraged.

Rather than discuss in detail here a selection of the common names found in this volume, let us examine some of the "ground rules" proposed by the Committee for its own guidance, for these express the philosophy behind the choices found in the list itself. On p. 1 we find:

"The Committee aims at the development of a body of common names that reflect broad current usage, the *creation* of a richer, more meaningful and colorful vernacular nomenclature, and the promotion of mechanisms that will add to stability and the universality of names applied to American fishes." (italics ours)

and on p. 2:

"The Committee believes that it is desirable to establish a common name for each species of fish occurring naturally or through successful introduction in the waters of English-speaking North America."

To this latter end the Committee has invented "common" names by the score if not by the hundred and has dignified with contrived names fishes which are far from common and others which have been known even to ichthyologists for but a few years. We have "common" names galore for groups of fishes still so poorly known that but a handful of professionals can distinguish the species with any degree of facility, while other perfectly good common names (for example all patronyms) have been arbitrarily thrown out. What sort of nomenclatorial twaddle is this?

As for "the creation of a richer, more meaningful and colorful vernacular nomenclature", the list essentially speaks for itself and should require no further comment. We but ask the reader to evaluate a few of these newly-coined common names: "stippled spoon-nose eel", "tropical two-wing flyingfish", "freckled driftfish", "widemouth blindcat", "seaboard goby" and others too numerous to list.

Certainly one of the Committee's statements (p. 1): "It is hoped, and the history of the recent past confirms, that common names may be more stable than scientific names," will irritate many a conscientious fish taxonomist. In a fauna still under study, name changes are inevitable; however, one of the taxonomist's objectives is a stable nomenclature. In contrast to the Committee's claims to common-name stability, the reader has only to compare the original common name list published by the American Fisheries Society in 1948 with the present list published 12 years later. A few changed names taken at random: *Elops saurus*, formerly bigeye herring, now ladyfish; *Alosa aestivalis*, formerly glut herring, now blueback herring; *Leucichthys artedi*, formerly shallowwater cisco, now cisco or lake herring; *Cyprinodon variegatus*, formerly variegated minnow, now sheepshead minnow; *Sebastodes pinniger*, formerly orange rockfish, now canary rockfish. It is interesting to note that of these five randomly-chosen species with changed names, only two have had scientific name changes within the past 12 years, and these are not at all universally accepted.

Equally unfortunate is the omission of all data underlying the selected choice of the common name. The Committee labored hard and long to select, from among competing names when known to them, the one which seemed most appropriate. Had the competing names and a brief account of the origin and current usage, together with the recommendation itself, been published we might be more disposed to accept the Committee's choices for those species which need a single preferred common name. The publication, however, of single preferred common names, indiscriminately mixed with various invented and replacement names of unstated origin and not identified as such, makes the list all but useless for those more than casually concerned with fish names.

By adhering to a set of principles and criteria which to us seem untenable, and by neglecting to publish the documentation to which the user of such a work is entitled, this Committee has produced a list which cannot be accepted *en bloc*, has entered a field of study not wholly its own and thereby added to the work of others confusion not of their own making, and has abused the common name concept. This need not have been, for the Committee has been formed from among the most expert ichthyologists in the United States and Canada and the List represents considerable effort which might have been directed toward a more satisfactory end. The correspondence and records of deliberations of the Committee must include source material most valuable in the study of American fish names: lists of competing names from which selections were made, local variations and barbarisms, derivations, and other data. There is also a substantial published literature concerned with such names, such as the series of papers by T. N. Gill. We hope that in some subsequent edition of the List, the Committee will restrict its activities to those groups of fishes for which single vernacular names are clearly mandatory and will publish an account of the origin and history of the name or names by which these species have been known.

Although the Committee itself clearly designates the names included as tentative and not nomenclatorially binding, the list will be widely circulated and the names contained therein will gain in usage. It will be on the shelf of many, from secretary to biologist and editor, for a search for a vernacular name, an "approved" name, or a correct spelling, is usually a bothersome irritant associated with a project of more immediate importance, and the list does carry the implied approval if not the official sanction of two professional societies and of the Committee itself. But our best wishes for a speedy recovery go to those true common names which may have been trampled in this superficial attempt at standardization.—**Giles W. Mead**, *Museum of Comparative Zoology, Harvard University, Cambridge 38, Mass.*, and **Daniel M. Cohen**, *U. S. Bureau of Commercial Fisheries, U. S. National Museum, Washington 25, D. C.*

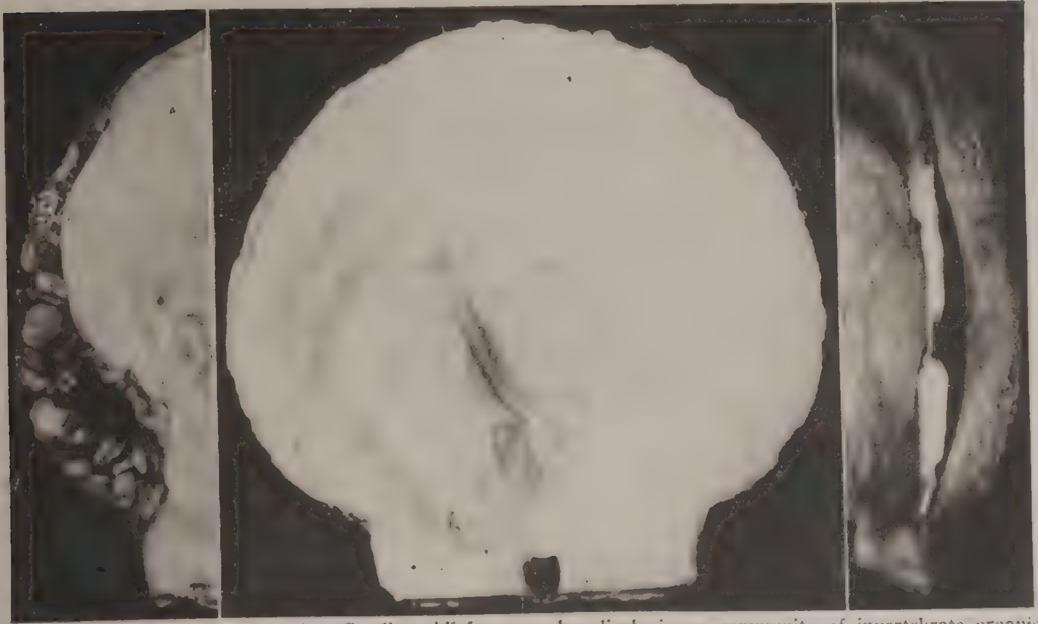
LIVING INCLUSIONS IN THE SHELL OF THE SEA SCALLOP *PLACOPECTEN MAGELLANICUS*

By

ARTHUR S. MERRILL

Reprinted from *Ecology*, Vol. 41, No. 2, April, 1960

LIVING INCLUSIONS IN THE SHELL OF THE SEA SCALLOP *PLACOPECTEN MAGELLANICUS*[1]



FIGS. 1-3. *Placopecten magellanicus* Gmelin. All from Cape Cod Bay, Massachusetts (about N. Lat. 41° 47′, W. Long. 70° 20′).

1. (center)—Interior view of left valve to show coating of new shell over mud-sand debris.

2. (left)—Interior view of an anterior portion of left valve displaying a community of invertebrate organisms within the periphery of the shell of the scallop.

3.—Oblique view of interior of posterior edge of right valve to reveal new shell material slowly being added toward margin.

A curious deformity of the shell is observed infrequently in the sea scallop *Placopecten magellanicus* (Gmelin). It occurs when foreign matter becomes lodged between the mantle and the shell. Unable to expel the material the animal secretes over it a protective barrier which prevents further injury or irritation (Figure 1).

An elaboration of this condition occurs when an excessive amount of foreign substance forces a portion of the mantle inward from its normal position along the margin of the shell. A protective barrier is secreted as usual but because of the awkward position of the mantle the new shell lining cannot reach the rim of the shell. Larval organisms are quick to take advantage of the scallop's predicament. They settle in the convenient niche within the protective lip of the shell and thrive in the currents created by the feeding of the scallop. The sensitive mantle margin of the scallop meanwhile begins to secrete a partition at the point of contact with the trespassers which prevents further invasion (Figure 2). If the scallop is later able to extend its mantle nearer the shell edge (Figure 3) it may cover or crowd out the fouling organisms, eventually reaching the border and ridding itself of the last of the intruders.

I have seen several examples illustrating various stages of the above condition. It is probably caused in many instances by the action of the scallop dredge used by commercial vessels as it scrapes up mud and sand along with the scallops. Often some of this mixture is forced between the valves and behind the mantle which, if the scallop escapes, occasionally creates the situation described above.

The method of repair is as follows. First the surface of the mantle membrane secretes a thick layer of dark organic substance similar in appearance to the "tanned proteins" of which the ligament in *Pecten* is constructed (see Trueman 1953). This organic product of the mantle is commonly referred to as conchiolin. Droplets resembling nacre[2] are deposited over the conchiolin usually starting the edge and working inwards but at times more or less at random. In this manner a foundation is quickly produced on which thin layers of "nacre" are then laid to create a thin crust. Areas in the crust frequently break causing an additional deposition of the organic matrix by the mantle surface over which more "nacre" is deposited. As layer after layer builds up the crust thickens. After the lining becomes substantial and the animal is protected, any slight depressions and rough spots are filled in until the inner shell surface is again relatively smooth.

The whole process of initial repair in the less serious cases is a matter of a short period of time, possibly only days. This can be ascertained by studying the edge of scallop shells that have undergone this type of repair. When a scallop has been disturbed a distinct

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[1] The author is indebted to Colonel Eugene S. Clark, Jr. for securing specimens of the sea scallop which exhibited living inclusions, and to Captain Richard Mayhew of the scallop vessel *Charlotte* who helped collect a series of deformed shells for further study.

[2] Nacre or mother-of-pearl always consists of aragonite In the *Pectinidae* the inner layer of calcium carbonate is crystallized in the calcitic form (Böggild 1930).

check forms at the edge and new growth can be recognized. New growth is apparent in recaptured tagged scallops after as short a period as 3 weeks.

Parker (1932) reported on a specimen of *Mya* in which a rhizome of *Spartina* had penetrated between the shell and mantle. Utilizing the winter growth-lines he was able to remark on the vigorous and active processes of recontruction to produce in a relatively short time a thick covering crust over the rhizome.

The organisms seen in the shell in Figure 2 are typical of those which are usually found in this situation in Cape Cod Bay, Massachusetts. Three species of bivalve mollusks made up the greater part of the inclusions.

Species	*No. of specimens*	*Size range (mm)*
Mytilus edulis Linné	30	0.3-14.6
Hiatella arctica (Linné)	28	1.1-14.8
Anomia aculeata Gmelin	23	1.5-15.0

Other invertebrate intruders in the shell were an encrusting bryozoan, some branching hydroids, a single polychaete annelid (Polynoidae), and 28 tiny barnacles, *Balanus* sp., 0.5 to 1.4 mm in diameter.

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ARTHUR S. MERRILL

U. S. DEPARTMENT OF THE INTERIOR, FISH AND WILDLIFE SERVICE, BUREAU OF COMMERCIAL FISHERIES, WOODS HOLE, MASSACHUSETTS

he American Fisheries Society

Its objectives: a chronicle of fishery conservation in North America

By Dr. James W. Moffett
Laboratory Director, U. S. Dept. Interior,
Fish and Wildlife Service

nce it was organized in 1870, the
American Fisheries Society has
ght diligently and with consider-
e success to recognize and solve
ery problems as the years present-
them. These problems have chang-
with the growth of the country and
h the interests of the people. For-
ately the Society has been able to
nge with them. It has always striv-
to keep its membership open to all
o had an interest in, and who felt
y had something to contribute to,
perpetuation and well-being of the
ery resources. It has always en-
avored to bring together these peo-
for frank and constructive discus-
n. Not the least of its objectives
been the dissemination of infor-
tion and the publication of worthy
coveries of the times.

The American Fisheries Society is
e of the oldest among the hundreds
organizations that have been es-
lished for conservation or for scientific purposes. Its origin paralleled that of the U. S. Fish Commission, the first federal organization that was set up to investigate, inventory, and find ways to maintain, the national capability to produce fish of varieties desirable to the public. Undoubtedly, many of the first members of the Society were instrumental in the formation of this agency.

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Society's Interest and Emphasis

As occurs in all organizations of long standing, the Society's fields of interest and emphasis have evolved and changed. So has the composition of the Society's membership. But, with every change, the noteworthy and constructive parts of each era have been retained and chronicled. The *Transactions* of the Society represent one of the oldest serials of fishery literature in existence.

Some of the changes in emphasis have come about with difficulty. Adaptation to new or different concepts was not without pain. There were times when factions of one sort or another threatened the very existence of the organization. All of the Society's problems of this kind are not in the past. New ones will arise to create their fields of controversy. We are fortunate that each scar of battle over constructive issues has strengthened and matured the group.

Evolution of Society

In discussing the evolution of the Society and its changes in emphasis, I would like to group them into stages. Of course, these stages did not start and stop suddenly. Gradual shifting of thought and action moved the Society from one stage to another almost imperceptibly.

The first of these stages might be called the formative period. It is founded in the basic needs and the cultural patterns that brought on the formation of the Society. It represents the boisterous, hard-working, short-sighted era of early national expansion. Our small population of the 18th and 19th centuries was intense in its empire building. Resources were used as though they would never be exhausted. We have only to refer to the classic examples of lumbering, mining, land, and water use to understand fully the atmosphere and drive of that time. This period is typified by such legends as Paul Bunyan and the exploits of his blue ox. This was the time when Great Lakes sturgeon were caught and stacked on the beaches because they were a nuisance — when the lake trout was cursed because it fouled the whitefish nets. "Spoil and move on" was the order of the day — not necessarily because we wanted to be that way but mainly because we knew of no alternative. The attributes of this stage did not disappear with the formation of the American Fisheries Society. Many of them still permeate our thinking and our courses of action. Consider, if you will, the present conflicts of interest in the field of water use.

Reflective Stage

The second, or "reflective stage" was slow in coming. Human populations were pushing outward in all directions. There was plenty of frontier but the bounties of nature were wearing thin in the settled regions. Mill dams were blocking abundant runs of Atlantic salmon and shad. Pollution, even then, was taking its toll of aquatic resources. Some people began to worry. They were becoming apprehensive about practices that used more than nature could supply. People like these formed the American Fisheries Society and worked hard to keep productive the aquatic resources they had at home. They represented a very small part of the population and were undoubtedly referred to as "cranks," alarmists, or rank pessimists. However, the disappearance of various fishes, such as grayling, trout, and whitefish from their accustomed places was causing general concern.

Inventory Stage

Out of the reflective stage grew the third or "inventory stage." People began to take stock of what they had in nature. Resources were reviewed and listed. Long, descriptive papers were prepared that catalogued the fisheries that were in trouble. Some attention was given to possible solutions but little was done to realize them. Because the concept of the people was based on the "practical and useful," little or no study of the fishes or the causes of their declines in abundance was undertaken. Records of production were compiled and flowing accounts of early fishing success were written. These form the basis of our references to the good old days.

As part of the inventory stage, inquiry was made into possible means of culturing fishes artificially. Many

Report of the 1960 Membership Committee

By Bill Bain, Chairman

(This report was presented at the U. S. Trout Farmers Assn. Convention in Denver in September)

During the past six months, the writer, as chairman of the membership committee, contacted the committee members by mail and proposed that a mailing be made to a list of private hatchery owners and managers engaged in propagating trout, advising them of the convention in Denver and extending them an invitation to attend the meeting and secondly, regardless of whether or not they were able to attend, to return an application for membership and to be a supporter of the U. S. Trout Farmers Association.

The mailing was made from our office in Newark, Ohio and should have been made at least 30 days earlier, but due to the fact that the association office had mechanical difficulties in running off the mailing lists; the mailing was delayed until the last week in August. This mailing was made to a selected 200 in the states of California, Colorado, New York, Pennsylvania, Minnesota and Idaho. As a result of this mailing we picked up by early September three new members: Krystal-Kleer Trout Hatchery, Lebanon, Pennsylvania; Happy Jack Trout Farm, 8041 San Gabriel Canyon Rd., Azusa, California; and Ozark Trout Farm, R. R. No. 1, Neosho, Missouri.

We still have hopes of receiving additional memberships from this mailing.

The experience to date, with the results of our mailing, which shows a return of approximately 5 per cent on the list mailed out, would indicate that it would be feasible for the membership committee to prepare a series of three mailings covering all of the trout hatcheries throughout the U. S. A.; all conservation officials of each state, where trout are propagated; reaching all suppliers and manufacturers of equipment or food products used in our industry; and all leading fishing tackle manufacturers, who by the way have a battle against imports, the same as our own industry.

The first task at hand would be to take the several thousand names on the association mailing list, have them thoroughly screened and classified. Secondly, to prepare with the assistance of our advertising agency, a series of three mailings, to be spaced approximately three weeks apart. As a result of these mailings, we should come up with 5 per cent of the total number of mailings in membership applications. In other words, based on our pilot mailing, heretofore covered, we should obtain fifty members at least for every thousand people contacted under this direct mail campaign.

The cost of the three mailings, including postage, is estimated at $300 per thousand, which on the basis of a 5 per cent return, would mean that the cost per new member would be approximately $6.00 each.

It would be our opinion that the coverage should be broad and on a national scale, as it stands to reason that the greater coverage of our membership throughout the country is important to support the activities of the association and enhancing the results of the association's activities.

The writer knows — from his own experiences in the four years that he has been a member of the association
— that every convention or meeti
that he has been able to attend h
offered information that was valuab
in hatchery operation. I feel con
dent that everyone who has attend
conventions of this kind and has be
a part of the meetings would confi
these statements emphatically.

May we suggest that members w
have any ideas on how to enhance
program, such as we have outline
sit down and write a letter to our n
president, Edward McLeary, so th
he can turn your suggestion and re
ommendation over to the chairman
the new membership committee.

The analysis of the problem
hand, as we see it, is to expose t
association to every potential memb
in all categories that should be ass
ciated with the U. S. Trout Farme
Association.

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migrants brought with them the now how" of carp culture and the le that was known about artificial wning and hatching of other spe- s. The art of fish culture caught on dily. It spread like wildfire. Almost ryone believed that his troubles re over. All they had to do was rn to spawn, hatch, and plant de- able varieties of fish to restore the unteous populations that fed their ndparents and furnished fun to the ak Waltons of their day. Each an- r dreamed of having his particular orite species right in his own back rd.

Restorative Stage

This good news and optimistic out- ok ushered in the fourth or "restor- ve stage." Hatcheries, private first, en public ones, by the score, sprang across the nation. Means of pro- gation of everything from codfish carp were developed. The Ameri- n Fisheries Society was composed most entirely of fish-culturists. Its *ansactions* were filled with articles how to produce hatchery fish. eryone hung his hopes on this new proach. Plans were ambitious. Fish many kinds were planted everywhere. Dreams of the ocean full of cod and other commercial varieties danced before the commercial fishing industry. Visions of 5-pound trout in every stream moved even the most skeptical angler. The records are full of new introductions and glowing accounts of what would result. Promises of a fishing paradise for everyone were in sporting and fishery magazines. Naturally, many mistakes were made. In their haste to replenish and develop fish stocks tailored to individual desires, no time was "wasted" on the life-history requirements of the species. The idea that only water and fish were necessary to assure success was dominant. Pacific salmon were introduced widely — even in the Mississippi River and its tributaries. Some of the upriver states feared that downriver states might catch all the fish before the upper states could get their share. Oysters were planted in Great Salt Lake in the hope that "blue points" would be produced locally. Carp were planted in many waters to the accompaniment of local brass bands. Holidays were declared to celebrate such events.

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a tributary to the Sacramento in California, was built in the 1870's and Livingston Stone was sent there by the U. S. Government to propagate and distribute salmon and trout. They were shipped all over the world. Salmon "took" in New Zealand and the trout, rainbow to us, succeeded in many waters. The stocks from this hatchery are ancestors to many of the rainbows now being reared and planted. Striped bass and shad were moved to the West Coast and established themselves. These are but a few of the many examples.

Results, generally were disappointing, however. The promised "fisherman's paradise" did not materialize and some introduced varieties of fish became nuisances. But, the majority of people still believed that because man had hatched these fish, they were blessed with immortality. All we needed to do was protect them more strenuously. The next or protective stage was ushered in with the promulgation of laws by the bookful restricting capture, closing seasons, setting size limits, and doing all sorts of things to give these fish the chance they needed to become established. It was reasoned that, left long enough, little fish would grow into big ones. Delicate species would become vigorous and paradise would again be restored. This movement is reflected in the volumes of the *Transactions* of the American Fisheries Society. Accompanying the protective stage was a rise in Society membership consisting of enforcement officers and administrators of newly formed fish and game departments entrusted with the protection of these renewable resources.

Gradually, through all of the preceding stages, there emerged individuals and small groups interested in the "why" of things aquatic. Most of these people were attached to universities and colleges. They were busy with learning fish life histories and requirements — why some waters were more productive than others and many other "long-hair" or "ivory-tower" studies. As time went on more and more articles and people in the Society were of this persuasion. Yes, some of them were highly vocal about the inadequacies of all the other disciplines that had gone before. Science was lauded as the new way to the fisherman's paradise. With the inclusion of science in fisheries, the investigative stage was born. From its inquiries and criticisms there developed knowledge that brought an end to certain malpractices and to policies that had been cornerstones in fishery ministration. There emerged a r concept called "fishery managemen As this approach gained in popul ity, its growth was reflected in Society's *Transactions* and its me bership. The fishery biologist and bag of tricks is currently one of dominant influences in practica every fishery agency. One needs o to look at the more recent progra of the Society to grasp the impact t group is exerting on fisheries gener ly. Perhaps this new approach is way. It looks promising — may because it is now in vogue. I, p sonally, do not expect it to pass. should assume a more important r in things as it develops more kno edge. Time alone will tell. Assured it will not provide the single pana to all fishery ills. The good poi of all the stages as chronicled in *Transactions* of the American Fish ies Society and represented by more than 2,000 Society members needed if we are to keep ahead the problems and the far-reaching c flicts of interest that the increas national population has created. T Society's objectives and purposes, stated in its present constitution, sure continuation of the valua work it has done during its 90 ye of existence. The objectives and p poses of the Society are:

"To promote the conservation, velopment and wise utilization of fisheries, both recreational and c mercial.

"To promote and advance the velopment and application of branches of fishery science and pr tice, including aquatic biology, er neering, economics, fish culture, l nology, oceanography and technolo

"To gather and disseminate t nical and other information on fis fishing, fisheries, and all phases fishery science and practice.

"To hold meetings for the pre tation, exchange, and discussion o formation, findings and experie on all subjects and techniques rel to fishes, fishing, fisheries, and phases of fishery science and p tice.

"By such other means as ma appropriate, to unite and encou those interested in fishes, fishing, eries and other phases of fis science and practice."

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1. Talk delivered at the 8th Annual Conven the U. S. Trout Farmers Association in T Colorado.

Reprinted from PACIFIC SCIENCE, *vol. XIV, no. 2, April, 1960*

Introduction of the Marquesan Sardine, *Harengula vittata* (Cuvier and Valenciennes), to Hawaiian Waters

GARTH I. MURPHY[1]

A PROGRAM of introduction of the Marquesan sardine was undertaken by the Bureau of Commercial Fisheries, Hawaii Area, at the request of the Hawaii Division of Fish and Game. The objective was to introduce a species of fish to the Hawaiian Islands that would be suitable as tuna bait in order to supplement the somewhat tenuous supply of the nehu, *Stolephorus purpureus* Fowler. The stimulus for the request and the subsequent program stemmed from the fact that the fish fauna of the Hawaiian Islands is notable for the number of endemic species and the absence of many forms that are common in the central Pacific islands to the south. Gosline (1955) proposed that the migration route of shore fishes to Hawaii is from the south and that Johnston Island, some 600 miles south of the Hawaiian chain, is the stepping stone. He suggests that the failure of many forms to reach Hawaii can be attributed to the large over-water distance to be traversed in crossing first to Johnston Island and then to Hawaii, to possible ecological screening of fishes at Johnston Island, and finally to the possibility that the Hawaiian Islands do not offer the necessary habitat for certain of the absent forms, especially in regard to species missing in Hawaii but found at Johnston Island.

The Marquesan sardine was first recorded as tuna bait by Royce (1954), who found them to be abundant and accessible in the Marquesas and suitable for tuna fishing. Additional factors suggested that they would be a useful and successful species in Hawaii. They were found along the surf line in the Marquesas but generally along rocky, sandy, sheltered beaches, a habitat not usually frequented by the nehu. (Thus, it did not seem likely that they would compete directly with the nehu.) The Marquesas are high, volcanic islands as are the Hawaiian Islands and, with the exception of the scarcity of coral in the Marquesas, appear to represent the same general type of environment as the Hawaiian Islands.

Negative factors relative to the introduction are the somewhat cooler water temperatures in Hawaii and the fact that our seasons are reversed.

Ordinarily, such an expensive project as transferring a marine fish from 10° south of the Equator to 20° north of the Equator would not be undertaken without an extensive investigation of the fish's life history to evaluate the chances of successful introduction and to weigh thoroughly the possibility that the species might do harm in the new area. The possibility of harm seemed remote, and the expense not critical because a program of introduction could be incorporated in an investigation of the Marquesas area by the Pacific Oceanic Fishery Investigations (now known as the Bureau of Commercial Fisheries, Hawaii Area).

The several releases in Hawaiian waters (Table 1) were made as close to shore as operationally feasible and in habitat situations that were regarded as suitable for the Marquesan sardine. Examination of the gonads of the sardines in Marquesas waters suggested that nearly all of the individuals brought to Hawaii were young, mature adults.

In lieu of an extensive recovery program, wide publicity was given to the releases and a special poster, which included a photograph of the sardine, was widely distributed throughout Hawaii wherever fishermen were likely to congregate. The poster was especially directed to tuna fishermen because they use fine mesh nets when fishing for the nehu. Relying primarily on tuna fishermen for recoveries has several obvious advantages and one serious disadvantage, for one would expect that the Marquesan sardine would not be most abundant in the same habitat as the nehu.

It is not the purpose of this discussion to

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[1] Fishery Research Biologist, Bureau of Commercial Fisheries, Hawaii Area, Honolulu, Hawaii. Manuscript received November 17, 1958.

TABLE 1
RECORDS OF THE MARQUESAN SARDINE (*Harengula vittata*) IN HAWAIIAN WATERS

RELEASES				RECOVERIES			
Date	Locality	Estimated number	Fork length (mm.) range and mean	Date	Locality	Number	Fork length (mm.) range and mean
12–17–55	Barbers Point, Oahu	11,000	66–115 (88)				
9–26–56	Hanauma Bay, Oahu	7,000	76–127 (101)				
				9–27–56	Kalihi Channel, Oahu	1	106
3–22–57	Pokai Bay, Oahu	27,000	78–116 (94)				
				3–26–57	Kaneohe Bay, Oahu	1	90
				3–27–57	Kalihi Channel, Oahu	1	90
				4– 8–57	Kaneohe Bay, Oahu	4	87–93 (91)
				6– 4–57	Kaneohe Bay, Oahu	1	103
				9– 9–57	Barbers Point, Oahu	6	120–145 (134)
12–14–57	Ewa, Oahu	31,000	90–111 (99)				
2–25–58	Ewa, Oahu	53,000	72–123 (98)				
				2–28–58	Honolulu Harbor, Oahu	4	82–101 (92)
				4–29–58	Pearl Harbor, Oahu	3	108–114 (111)
5– 2–58	Ewa, Oahu	8,000	47–134 (102)				
6–23–58	Maunalua Bay, Oahu	3,000	84–115 (101)				
				6–27–58	Honolulu Harbor, Oahu	1	102
				6–30–58	Kaneohe Bay, Oahu	1	105
				7– 5–58	Kihei, Maui	10	Not examined
				9–10–58	Port Allen, Kauai	6	67–72 (70)
				9–23–58	Kaneohe Bay, Oahu	1	62
				9–25–58	Hanalei Bay, Kauai	6	74–84 (80)
				10– 2–58	Port Allen, Kauai	6	43–84 (71)
				10– 7–58	Kihei, Maui	29	37–61 (52)

evaluate the program completely to date; the passage of time will furnish definitive information in this respect. The pattern of recoveries in Table 1 however does permit optimism. The first release yielded no recoveries and the second was followed the next day by a single recovery. There were no additional recoveries until a few days after the next release on March 22, 1957, about six months later. It is significant that this planting was nearly three times as large as its predecessors and was followed by a number of recoveries culminating in the capture of six large adults off Barbers Point by a fisherman, using a gill net. This recapture was significant because (1) the fish recaptured were larger than any planted in Hawaiian waters (in fact the largest were longer than any measured in Marquesan waters), and (2) examination of the specimens suggested that they were very close to spawning. There were no additional recoveries for another six months and these followed close on the heels of an additional release, as did the two recoveries in June, 1958.

In July, September, and October, 1958, there were recoveries that did not fall into the usual pattern. First, the sardine was reported from Kauai and Maui where they had not been planted, and, perhaps more significant, some of the specimens were very small in size, strongly suggesting that there had been successful reproduction.

Of 1,300 fish measured in the Marquesas during the spring of 1958, only 81 were smaller than 75 millimeters. Considering only the last two stockings, only 3 of 50 fish measured were less than 75 millimeters and these were planted in May of 1958. For these small specimens to have originated from the stockings would require both that the fish did not grow during their three or four months' stay in Hawaii, and that there was a highly improbable statistical accident. In view of the growth evinced by the six specimens taken off Barbers Point on September 9, 1957, this seems remote.

In summary, substantial numbers of Marquesan sardines have been released in Hawaiian waters; there have been numerous casual recoveries by commercial fishermen in Hawaii, all indicating that the individuals released were healthy. Finally, there is now at hand good evidence that the species has spawned. To the writer's knowledge, this is the first successful introduction of a purely marine fish species; perhaps the success is not unexpected because of the general impoverishment of the Hawaiian marine fauna and the attendant vacant niches. This type of faunal impoverishment has generally been the basis of the numerous successful fresh water introductions of exotic fishes.

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Thirty-fifth Annual Meeting, 1959-60.
Published by the University of Hawaii, Honolulu, Hawaii, 1960.

4. CONFINEMENT OF SKIPJACK IN A POND[1]

The skipjack tuna (*Katsuwonus pelamis*), locally own as aku, is the most important commercial fish Hawaii. This species of tuna, which is distributed roughout the warmer seas of the world, represents resource of protein capable of a much greater yield an the amount presently being harvested. One phase the research at the Honolulu Biological Laboratory the development of more efficient methods of harvest-g this resource. Clues for the development of such ethods are being sought through investigations of ipjack behavior.

One part of the behavior investigations is the study skipjack responses to various stimuli. A requisite r this study is the control of environmental condi-ons of the test fish. Such control can be achieved st with captive skipjack maintained in tanks or nds.

A pond, 23 feet in diameter and 4 feet deep, was stalled at Kewalo Basin. This circular pond was lled with water from an adjacent salt water well. his water is less saline and more acidic than open ean water and practically devoid of oxygen. It oxygenated by allowing it to cascade through an rator of special design.

Initial attempts to establish skipjack in this pond ere unsuccessful. The fish, which were caught at a by the live-bait method, were transported to the pond in the live-bait wells of the "Charles H. Gilbert," research vessel of the HBL. The transfers from the sea to the bait wells and from the bait wells to the pond involved considerable amounts of manual handling of the fish. None of these fish survived for more than two days.

A new method was tried in February, 1960. Skipjack were captured at sea by the same method but from a commercial fishing vessel. Immediately after capture and while still suspended from the hook, the fish were lowered into a portable steel tank, 6 feet wide, 8 feet long, and 25 inches deep. At Kewalo Basin, the tank was lifted off the vessel and lowered into the pond. A hatch in the side of the portable tank was opened and the fish allowed to swim out.

Skipjack handled in this manner soon adapted to conditions of captivity and were successfully induced to feed on dead food. Five skipjack of about 3 pounds in size have been held in confinement for over 12 weeks and have been feeding daily on pieces of shrimp and squid.

EUGENE L. NAKAMURA
U. S. Bureau of Commercial Fisheries
Honolulu, Hawaii

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[1] Published by permission of the Director, U. S. Bureau of Commercial Fisheries.

Seasonal Distribution of Some Epipelagic Fishes in the Gulf of Alaska Region[1]

By Ferris Neave

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Biological Station, Nanaimo, B.C.

and M. G. Hanavan

United States Fish and Wildlife Service
Seattle, Washington

ABSTRACT

Distribution of various species of fishes in the Gulf of Alaska region in early, middle and late summer of 1956 and 1957, as determined by fishing with surface gillnets, is plotted.

The surface area occupied by steelhead and by four species of Pacific salmon is considerably reduced during the progress of the season. There is a large northward shift of the northern limits of distribution of pomfret, blue shark, jack mackerel and albacore during the same period. There is no obvious seasonal change in the distribution of the salmon shark.

Seasonal changes in range of occurrence conform with temperature changes in the surface waters and are more extensive in the eastern part of the Gulf.

INTRODUCTION

In the fishing operations conducted on the high seas of the North Pacific since 1955 by research vessels implementing the program of the International North Pacific Fisheries Commission, emphasis has been placed on the problem of determining the areas of origin of the salmon found in various regions of the ocean. These operations, however, together with associated oceanographic surveys and observations, have also yielded information on general features of the distribution not only of salmon but of other species inhabiting the surface waters of the high seas.

In spite of the fact that fishing in these offshore waters has been limited to a period extending from May to September, pronounced seasonal changes in the distribution of various species have been found. Such changes are especially evident in the extensive range of latitude which has been covered by research vessels in and immediately south of the Gulf of Alaska.

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[1] Received for publication September 25, 1959.

J. Fish. Res. Bd. Canada, 17(2), 1960.
Printed in Canada.

MATERIAL AND METHOD

The data which are used in this account were obtained in 1956 and 1957 by the following United States and Canadian vessels:

1956. United States: *Celtic, Mitkof, Paragon, Tordenskjold, John R. Cobb.*
Canada: *Key West II, Challenger.*

1957. United States: *Attu, Paragon, Pioneer.*
Canada: *Key West II, Fort Ross.*

In addition, certain records pertaining to the distribution of salmon and albacore made in the southern part of the region in 1956 by the United States vessel *John R. Manning*, operating from Hawaii, have been included.

The only gear used in compiling the record consisted of floating gillnets hanging from the surface to a depth of 20 feet. Four sizes of mesh were used, namely, 2½, 3¼, 4½ and 5¼ inches. The total length of nets set on each occasion varied from 300 to 2050 fathoms but was usually 900 fathoms or more.

Species whose size and habits make them vulnerable to such gear, and which are also sufficiently plentiful to provide seasonal comparisons, are not numerous in the offshore waters of the Gulf of Alaska. They include, however, the salmon shark (*Lamna ditropis* Hubbs and Follett); blue shark (*Prionace glauca L.*); coho salmon (*Oncorhynchus kisutch* Walb.); sockeye salmon (*O. nerka* Walb.); chum salmon (*O. keta* Walb.); pink salmon (*O. gorbuscha* Walb.); steelhead (*Salmo gairdneri* Richardson); pomfret (*Brama rayi* Bloch); jack mackerel (*Trachurus symmetricus* Ayres); albacore (*Thunnus alalunga* Bonnaterre).

The dates and positions of fishing stations, water temperatures and other information have been published in the Annual Reports of the International North Pacific Fisheries Commission for 1956 and 1957.

FINDINGS

Approximate fishing positions are shown in Fig. 1 to 7. They are grouped in three categories representing early, middle and late summer. The earliest records in the first group were about the middle of May. The latest dates for fishing were about September 20. The places at which catches of each species or group of species were made are represented by solid symbols. Symbols show presence or absence in the hauls. They do not make allowance for differences in quantity of gear or in number of fish caught. Some salient features of the diagrams are noted:

Salmon Shark. This species was caught much more frequently in late summer than in the months of May, June and July. There is, however, no obvious pattern of seasonal change in distribution (Fig. 1). Although early season records for the species in the northern part of the Gulf of Alaska are wanting, it is probably present there, since it has been taken in June at Latitude 55°N in the Bering Sea. It is possibly the only sizeable species of fish which can be expected to occur in the surface waters of all parts of the region under discussion at all seasons of the year.

PACIFIC SALMON. In Fig. 2 the four species of *Oncorhynchus* which were commonly taken in high seas fishing are treated as a single unit, since the differences in limits of distribution which may exist between them are too small to be apparent in a broad survey based on widely scattered observations. In May and June Pacific salmon were consistently present in catches made north of Latitude 45° or 46°N off the Washington coast. They were not present in lifts made a short distance farther south.[2] In July a restriction of distribution was apparent. By August there appeared to be a large region west of Vancouver Island and the Washington coast in which Pacific salmon were not available to offshore surface gillnets.

STEELHEAD. The seasonal pattern of catches (Fig. 3) is very similar to that of Pacific salmon.

POMFRET. All early summer catches of pomfret were made at or south of Latitude 50°N. With the progress of the season the species spread throughout the Gulf (Fig. 4).

BLUE SHARK AND JACK MACKEREL. These two unrelated species showed similar patterns of distribution (Fig. 5, 6). Early summer occurrences were restricted to the extreme south or southeast portion of the region investigated. During middle and late summer a large expansion of range took place. This expansion, however, was mainly confined to the eastern part of the Gulf.

ALBACORE. No albacore were taken in the region until after the middle of July. In August or September of both years the species was caught at Latitude 50°N in the eastern part of the region (Fig. 7).

TEMPERATURE

Surface temperatures encountered during these investigations ranged from 7.6°C to 17.2°C.[3] These limits are insufficient to cover the full range of tolerance of any of the species concerned. However they appear to embrace the highest

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[2] While the ocean distribution of salmon at other seasons of the year is little known, in April, 1956, pink salmon were taken as far south as 41°28′N at Longitude 165°W by the United States vessel *Charles H. Gilbert* operating from Honolulu. It is possible that in the mid-Pacific the winter range extends even farther to the south, as surface temperatures below 13°C were reported on this meridian as far south as 38°N.

[3] Excluding a single set by the *Tordenskjold* on the edge of the region (Lat. 53°N. Long. 165°W, May 31, 1956) which showed a temperature of 4.1° and yielded sockeye and chum salmon.

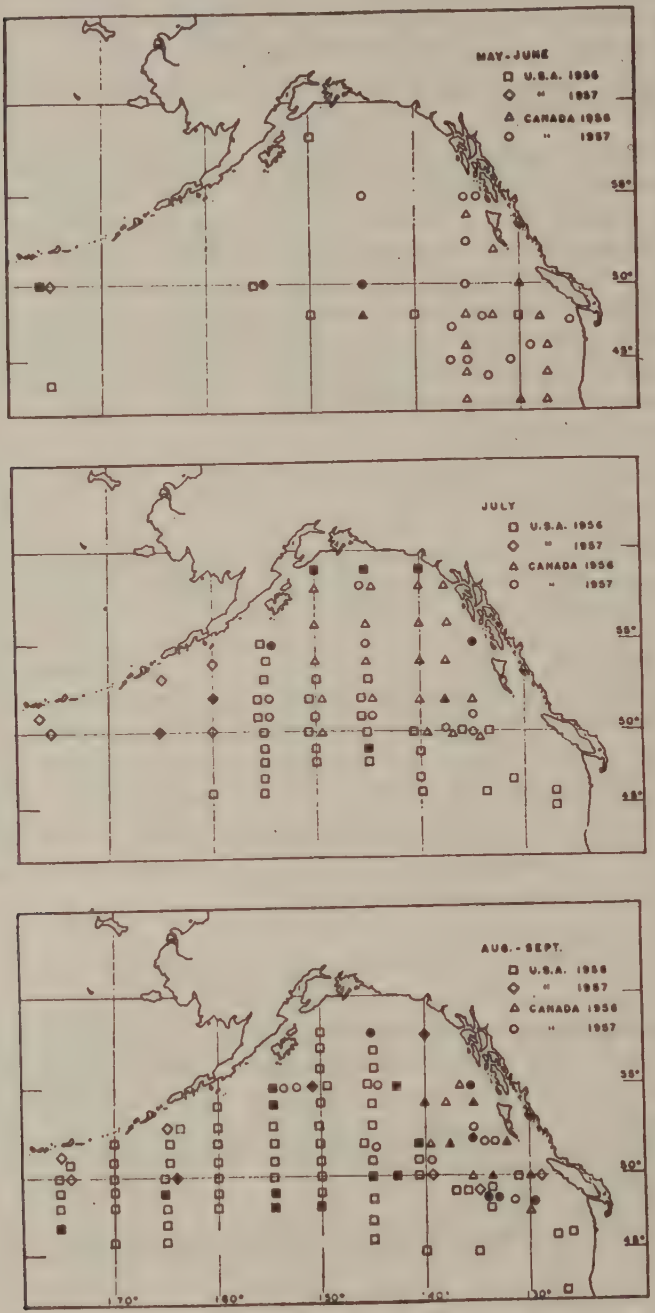
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FIG. 1. Distribution of the salmon shark. (In Fig. 1 to 7, black symbols indicate occurrences, open symbols indicate fishing stations where the species in question was not taken.)

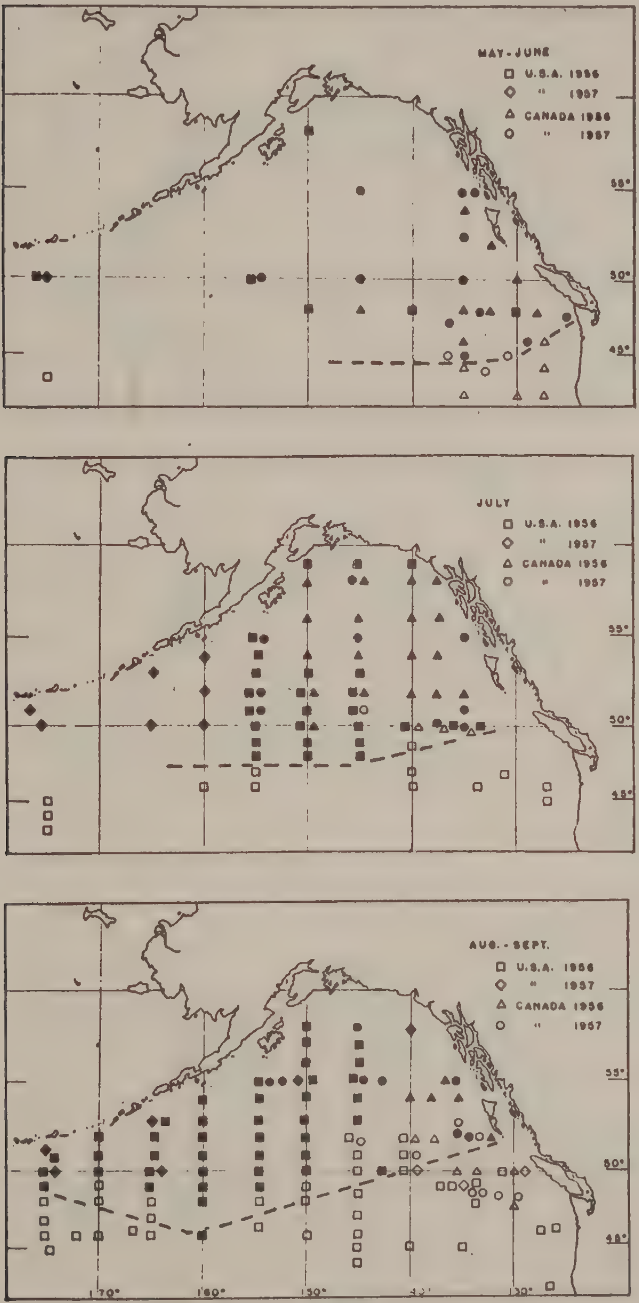
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FIG. 2. Pacific salmon. The broken line represents the approximate southern limit of catch records.

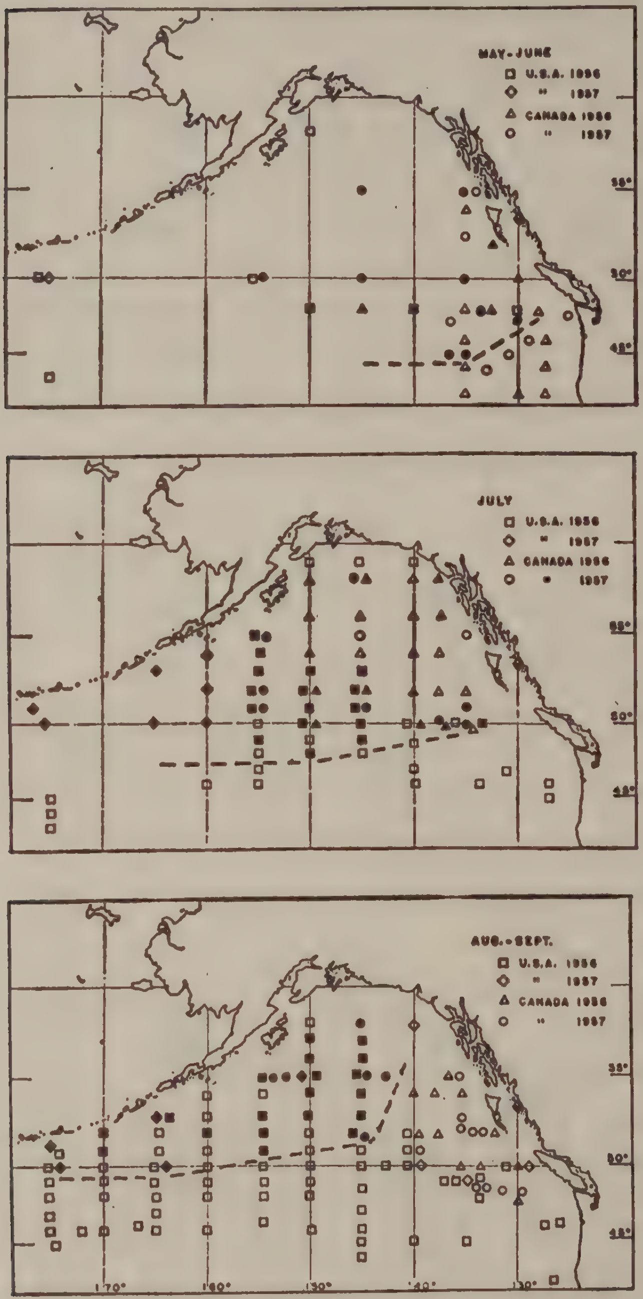
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FIG. 3. Steelhead. The broken line represents the approximate southern limit of catch records.

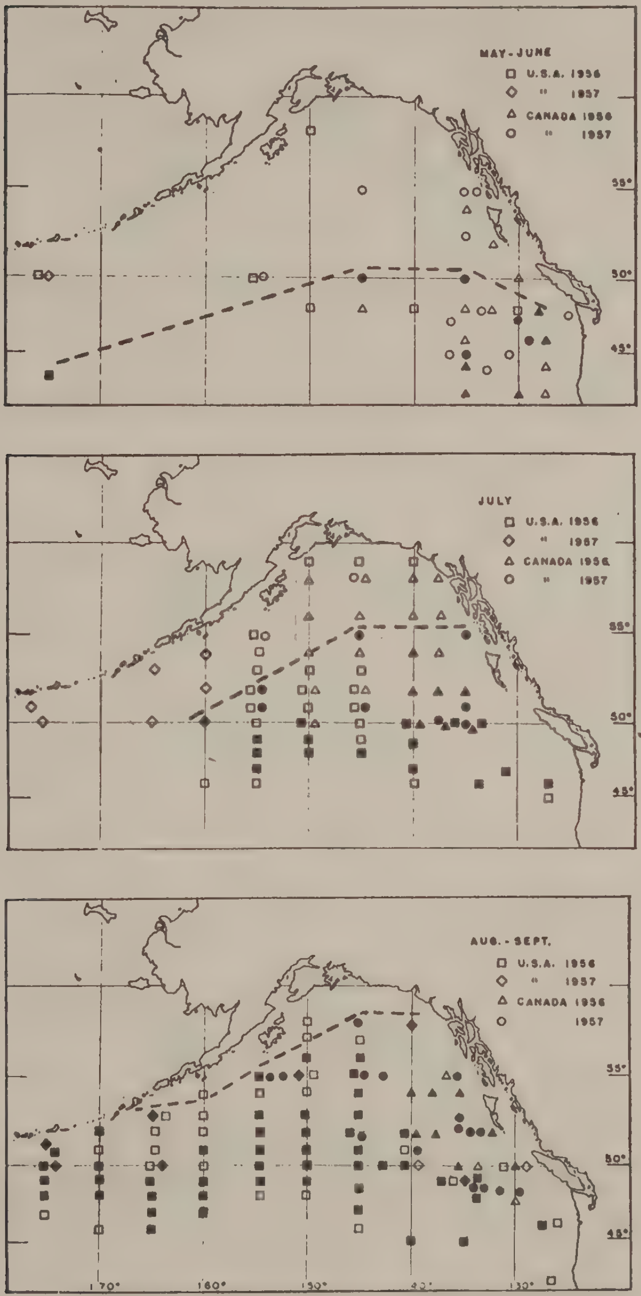
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FIG. 4. Pomfret. The broken line represents the approximate northern limit of catch records.

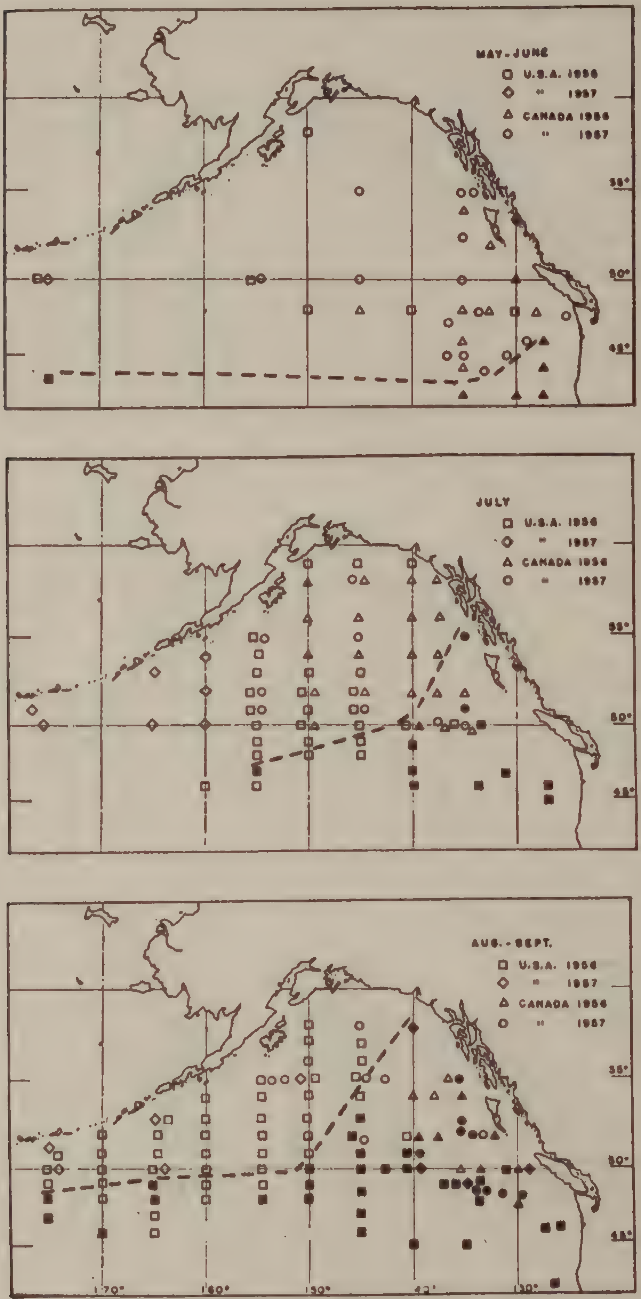
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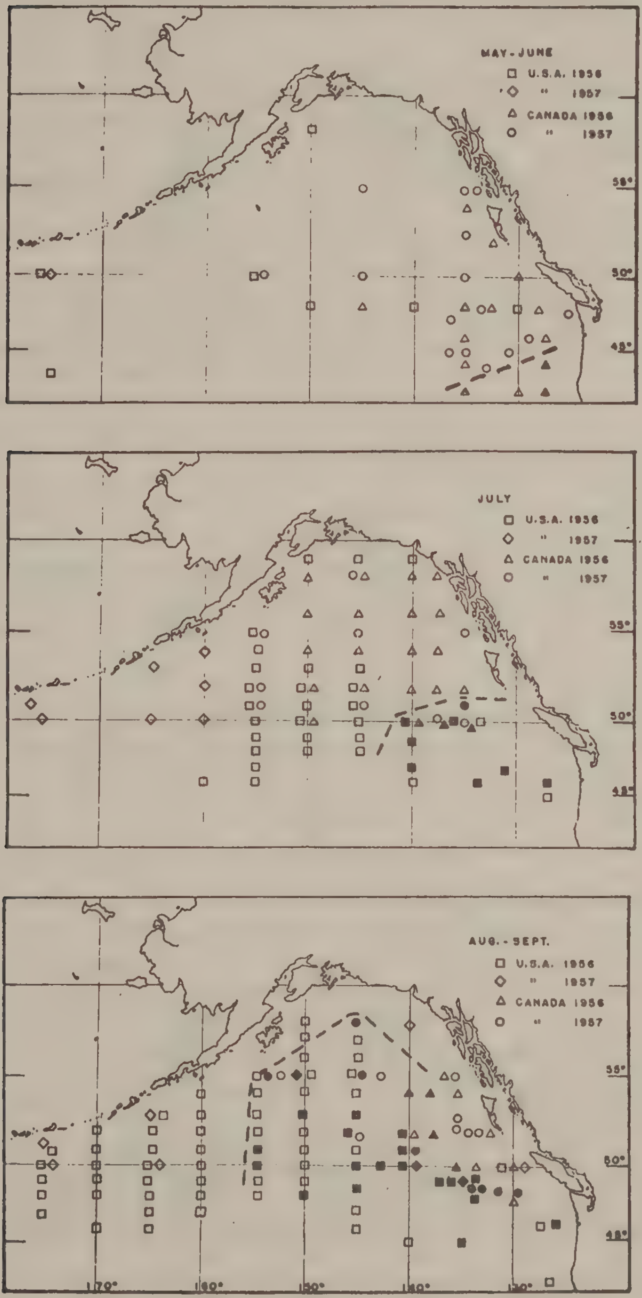
FIG. 5. Blue shark. The broken line represents the approximate northern limit of catch records.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130°

FIG. 6. Jack mackerel. The broken line represents the approximate northern limit of catch records.

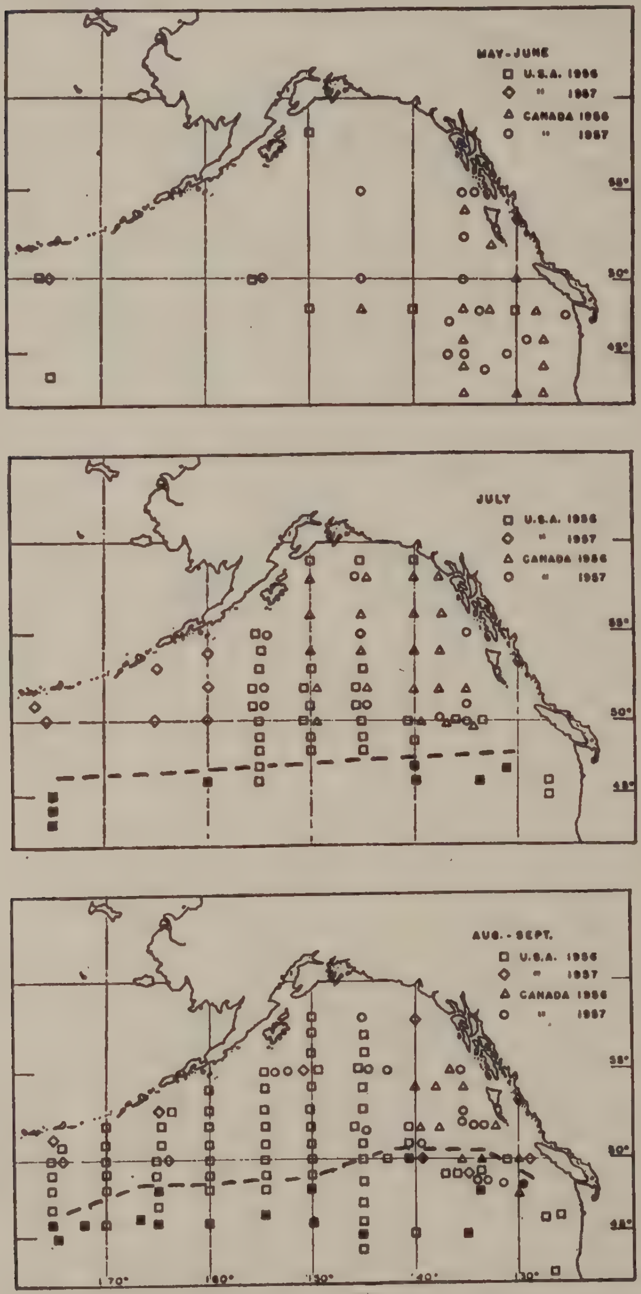
MAY-JUNE
□ U.S.A. 1956
◇ " 1957
△ CANADA 1956
○ " 1957
55°
50°
45°
JULY
□ U.S.A. 1956
◇ " 1957
△ CANADA 1956
○ " 1957
55°
50°
45°
AUG.-SEPT.
□ U.S.A. 1956
◇ " 1957
△ CANADA 1956
○ " 1957
55°
50°
45°
170°
160°
150°
140°
130°

FIG. 7. Albacore. The broken line represents the approximate northern limit of catch records.

favourable temperatures for growing salmon and steelhead and the lowest temperatures in which pomfret, blue shark, jack mackerel and albacore commonly occur (Fig. 8).

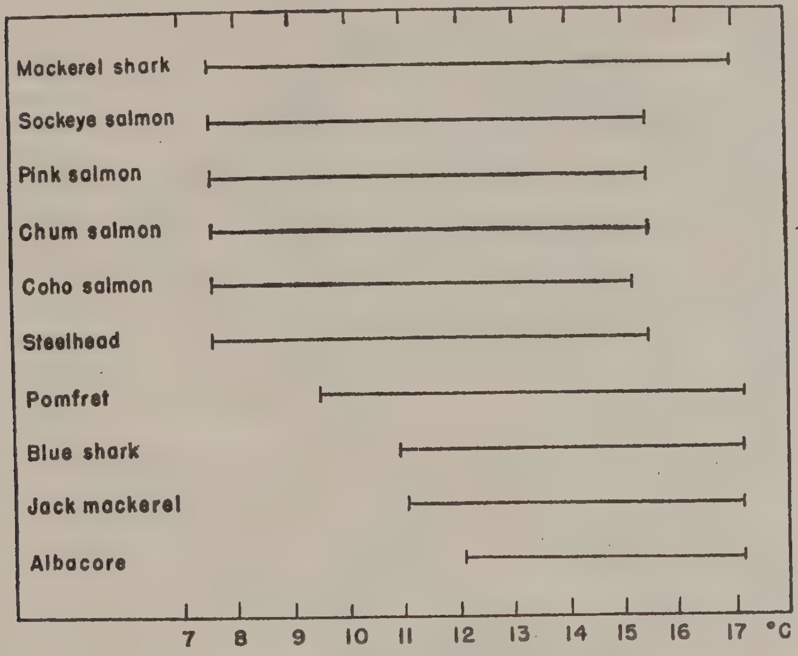

FIG. 8. Temperature range recorded for epipelagic fishes in the Gulf of Alaska region.

DISCUSSION

The locality records indicate the occurrence of broad directional movements for all the species discussed except the salmon shark. The distribution patterns conform with the general pattern of near-surface isotherms (Fig. 9). In accordance with the latter the northward withdrawal of cold-water species and the intrusion of warmer-water species during the summer are much more pronounced in the eastern part of the Gulf than farther west.

On the basis of two years' data the surface distribution of salmon in the region shrinks by some 300,000 square miles (777,000 km^2) between early and late summer. A similar restriction of range is evident for the steelhead. Data are not yet available to show whether salmon and steelhead are present in this area at depths below the fishing range of surface gillnets.[4] However, if temperature

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[4] On occasions when surface temperatures exceeded 15° (the approximate upper limit at which salmon were caught) water of this temperature was usually present within 25 metres of the surface.

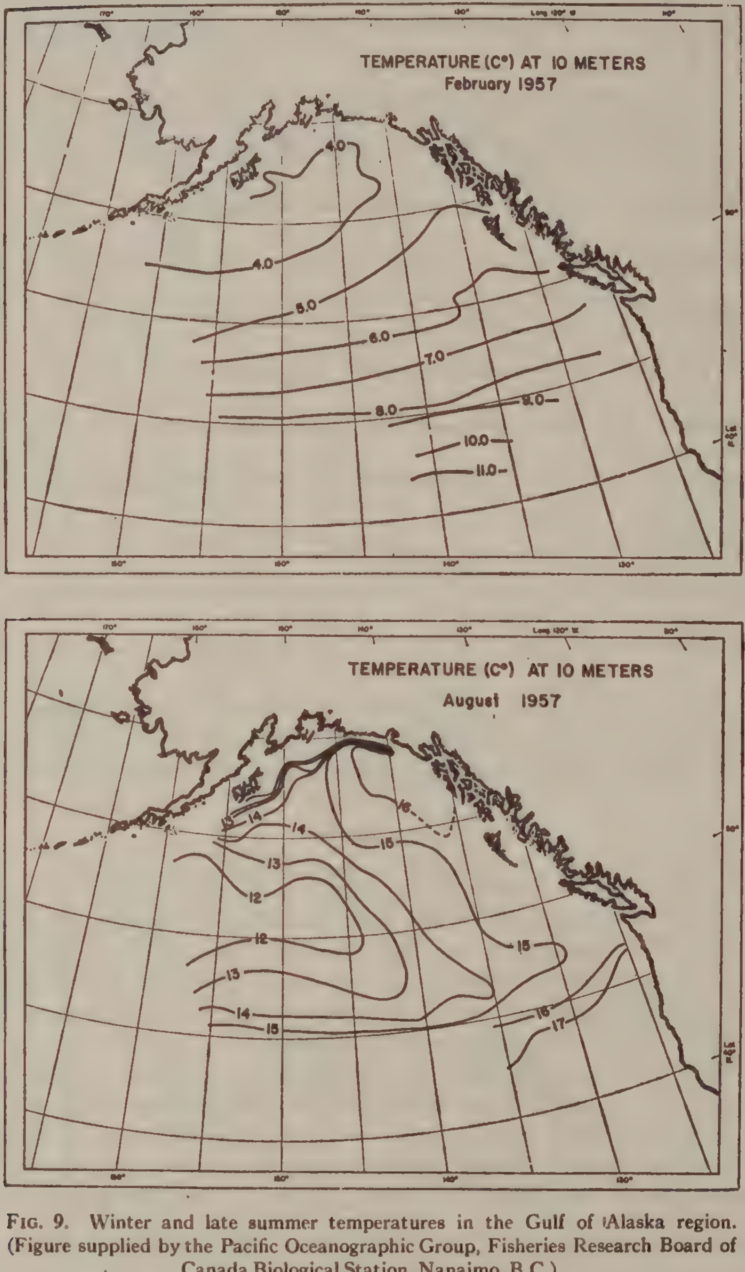
TEMPERATURE (C°) AT 10 METERS
February 1957
4.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
TEMPERATURE (C°) AT 10 METERS
August 1957
13
14
14
15
16
13
12
12
13
14
15
15
16
17

FIG. 9. Winter and late summer temperatures in the Gulf of Alaska region. (Figure supplied by the Pacific Oceanographic Group, Fisheries Research Board of Canada Biological Station, Nanaimo, B.C.)

is the main factor limiting distribution the surface records could certainly be expected to show horizontal changes of territory in the case of species coming from the south. These records suggest a seasonal expansion of range for jack mackerel, blue shark and pomfret amounting to from half to three-quarters of a million square miles (1,300,000 to 2,000,000 km^2) in the Gulf region. The boundaries drawn for these species in early and late summer indicate that the distances travelled in a northward direction by some fish during this period would be at least 500 sea miles (900 km) for pomfret, 700 miles (1300 km) for blue shark and 800 miles (1500 km) for jack mackerel. Inspection of dates and localities within a given year suggests that during the migration some pomfret average 8 or 9 miles (15–17 km) of northward movement per day and some jack mackerel 13 or 14 miles (24–26 km). Presumably the survivors of these summer invaders undertake a return migration later in the year, but of this nothing is known.

The annual variations which may occur in the territory occupied by the various species cannot be determined from two years' data. Surface water temperatures in the Gulf of Alaska were above average in the summer of 1957 and averaged 1° or 2° warmer than in 1956. A comparison between the findings of these two years suggests that this factor may have influenced the northern limits attained by blue shark and jack mackerel (Fig. 5, 6). However the main features and general scope of the seasonal changes in distribution seem to have been very similar.

Proceedings of the Montana Academy of Sciences 19:84-90. #49

Relationship of Fish Size and Water Velocity to the Fish Guiding Effectiveness of a Single-Row Electrode Array

H. William Newman and Alan B. Groves

Providing safe passage for fingerlings around obstacles is a major underaking of fishery, reclamation, power, and flood control agencies in the Pacific oast region. Investigations into this problem have included attempts to utilize creens, louvers, sound, pumps and electricity. Of these means, perhaps the one reating the most interest has been the use of electricity for guiding fingerlings.

The U. S. Fish and Wildlife Service began a systematic program in 1951 to evelop electrical fish screens. This program, begun as laboratory studies at the eattle Biological Laboratory (formerly known as Pacific Salmon Investigations), s now undergoing large-scale field trials at Lake Tapps in Pierce County, Washngton. Laboratory tests have outlined the factors which contribute to mortality (3), conditions which are best for electrical control of swimming, types of eectrodes and array orientation (9), duration and frequency of pulsed d.c. (8), and orientation of the electrical field with respect to water flow.

The purpose of this report is to present data of an experiment designed to test the relationship of both fish size and water velocity to the fish-guiding effectiveness of a single-row electrode array. Since we realized early that fish of different sizes are affected to a different degree by an electrical field, we had planned to experiment with fish size as a variable. The results of field trials in the spring of 1955 indicated that certain unknown factors at times reduced guiding effectiveness. Laboratory explorations into the problem indicated that water velocity might be a significant factor. Therefore, water velocity and fish size were examined simultaneously in August of 1955.

Materials and Methods

The facilities (Fig. 1) used for these tests imposed certain limitations on the attainable water velocities, which ranged from 0.28 feet per second to 0.56 feet per second. At the upstream end of the experimental area a screened baffle restricted the fish and spread the water flow across the entire area. At the downstream end of the experimental area two raised gates could be released remotely to hold the fish in the trap areas. The downstream ends of the traps were screened just ahead of the pump intakes. The electrical array was placed diagonally across the experimental area at an angle of 40 degrees to the water flow with the lower end at the junction of the two gates. Fish were introduced from a pail suspended from a fixed point near the upstream baffle.

We apportioned the width of the experimental area with the trap gates at the lower end of the array to represent guiding and nonguiding sections. The guiding portion was one third while the nonguiding portion was two thirds of the total width. This division combined with positioning of the fish release point on the array side insured that as small a number of fish as possible would pass into the diversion channel due to chance alone when the array was not electrified. We felt that a chance distribution of 50-50 is not realistic when establishing criteria for guiding fish in streams.

Three water velocities were used: 0.28 feet per second; 0.45 feet per second; and 0.56 feet per second.

During the experiment the water temperature fluctuated, with daily weather changes, between 62 and 67° F. The depth of the running water was approximately 12 inches. The electrical resistance of the water was maintained at 3,900 ohms per inch cube by the addition of fresh water or table salt.

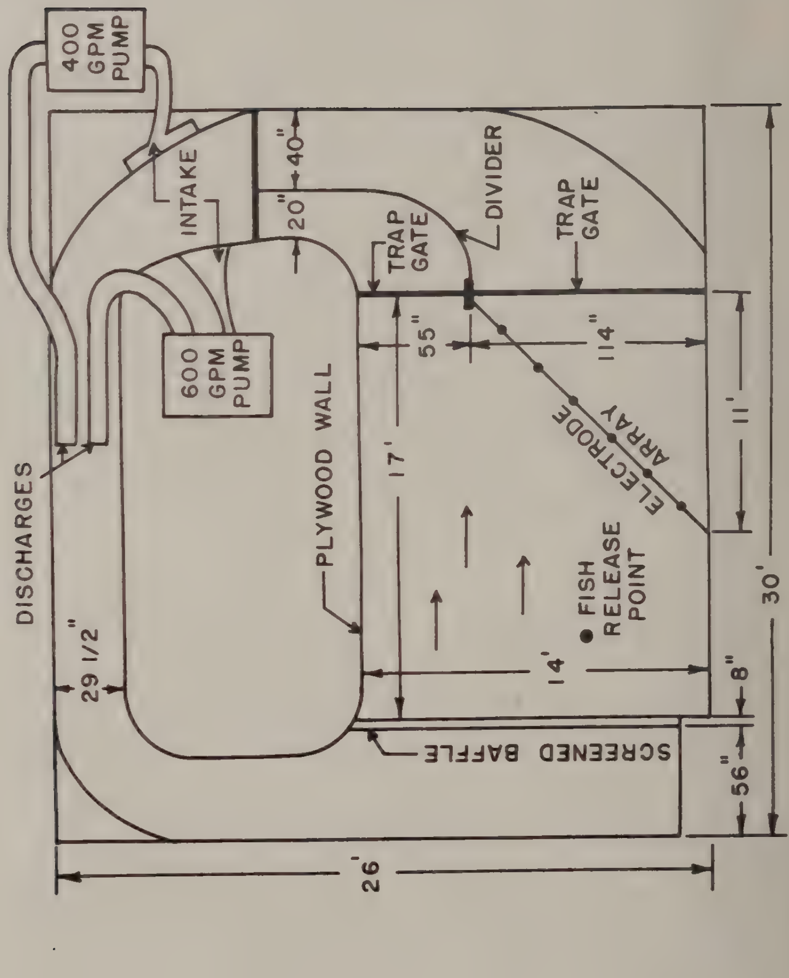
400 GPM PUMP
INTAKE
600 GPM PUMP
DISCHARGES
29 1/2"
PLYWOOD WALL
20"
40"
TRAP GATE
DIVIDER
TRAP GATE
55"
114"
17'
11'
ELECTRODE ARRAY
FISH RELEASE POINT
14'
8"
30'
SCREENED BAFFLE
56"
26'

Figure 1.--Plan of experimental tank. Diverted fish are captured in narrow channel

With the same electrical generating and control equipment which was used in the preceding test 1/, we established the following electrical conditions: Direct current was pulsed in "square waves" at a frequency of three pulses per second and a duration of 30 milliseconds; the pulsed current was applied at a potential of 210 volts across electrode spacings of 30 inches; at each pulse the entire array in the water was energized and at each pulse the polarity of each electrode was reversed.

Silver salmon fingerlings (*Oncorhynchus kisutch*) of three distinct sizes were obtained from hatcheries of the Washington State Department of Fisheries. We held the largest fish from the brood of the previous year (Issaquah hatchery) but fed them a reduced diet to prevent too great a growth. The next size came from the brood of the current year, also from the hatchery at Issaquah, and the third group from the brood of the current year from the Toutle River hatchery where low water temperature depressed the growth rate. Thus, these size ranges (or length) were available: 86-120 millimeter total length, mean of 105 millimeters; 70-90 millimeter total length, mean of 80 millimeters; 40-74 millimeter total length, mean of 59 millimeters.

Every effort was made to reduce extraneous stimulation of the fish before releasing them in the experimental tank. The fish required for a day's tests were left to settle over night in separate compartments of light-proofed holding troughs adjacent to the experimental tank. The tests were conducted in the same manner as those described by Newman.

The experiment was designed as a block of nine treatments repeated on nine days. "Power off" controls were not required because each combination of variables was repeated each day at a different time. Fifty fish were released in each trial. The total number of fish recovered from the traps was 3,112; these constituted the sample for analysis. Fish which remained above the array were removed after each trial but were not considered as part of the sample. The number of fish captured in the narrow channel was related as a percentage to the total number caught in both traps.

Results

The experimental design and the data of each day with preliminary tables of statistical treatment are not included in this report. However, they are available as a supplement in processed form from the authors.

The numbers of fish recovered in the narrow channel for each fish size and for different water velocities and the total numbers of fish recovered downstream in each case are shown in Table 1.

Table 1. Guiding influence under different velocities and different fish sizes.

	Total Downstream	Guided		Total Downstream	Guided
"Small fish"	794	322	"Low velocity"	885	378
"Medium fish"	1,072	423	"Medium velocity"	1,056	393
"Large fish"	1,066	445	"High velocity"	1,171	418

The mean data, grouped by water velocities and fish sizes, are shown in Table 2 and give a comparison of the effects of the velocities and fish sizes. These data were analysed for differences between water velocities, days, and fish sizes

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1/ Newman, H. William, MS. "Effect of field polarity in guiding salmon fingerlings by electricity."

Table 2. Mean guiding effectiveness by classification with respect to fish size and water velocity. Percentages are based on total numbers for each condition.

	Water Velocity			
Average Fish Size	0.28 Ft./Sec.	0.45 Ft./Sec.	0.56 Ft./Sec.	Overall Mean
59 mm.	36.3%	34.5%	29.4%	32.5%
80 mm.	49.3	35.9	35.6	39.4
105 mm.	42.0	41.3	41.9	41.7
Overall Mean	42.7%	37.2%	35.7%	

as shown in Table 3.

Table 3. Analysis of variance.

Source	Sum of squares	Degrees of freedom	Mean square	F
Fish size	369.47	2	184.735	6.252**
Water velocity	260.29	2	130.145	4.404*
Interaction	245.47	4	61.368	2.227
Days	300.44	8	37.555	1.271
Error	1,763.95	64	27.562	
Total	2,939.62	80		

** Highly significant
* Significant

In tests previously completed, Newman (op. cit.) used fish equivalent to th large size (84-129 mm.) and a water velocity close to the high velocity (0.50 fe per second). With an alternated polarity condition of energizing the array a me guiding effectiveness of 42.8 percent was obtained; the random distribution duri "power off" was 15.8 percent. This random distribution cannot be used here to reveal the true effect of the electrical barrier, but it serves as a relative ba and suggests that about one third of the guided figure is due to random movement

Discussion and Conclusions

Fish Size

Fish size may vary the effectiveness of an electrical field because of two conditions. First, fish size has a direct relationship to the electrical stimul received. Second, fish of increasingly larger sizes are able to maintain positi better at a given velocity.

Various experimenters have noted that the amount of electric current receiv (or the magnitude of the stimulus) is effected by the size of the fish. Groody, Loukashkin and Grant (6) say, "The current density required to produce direction swimming appeared to vary inversely with the size of the fish tested." Bary (1) graphically shows the relationships of fish size, electrical potential, and minimum response or electrotaxis.

In the instances cited above, fish size has a direct relationship to the effectiveness of an electric field. This agrees with our data in which there is an increase in effectiveness at each velocity of water due to increase in fish size (Table 2). This increase in effectiveness is highly significant for all elocities combined (Table 3). The linear effect (over the range tested here) f fish size on guiding effectiveness is shown in Figure 2.

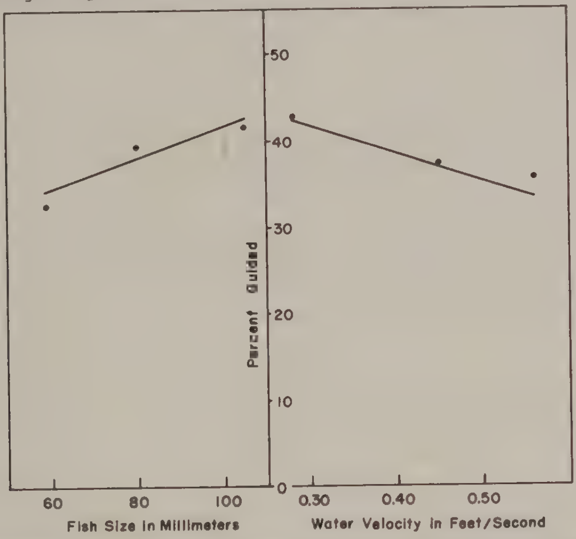

Fig. 2. The effect of fish size and water velocity on the guiding effectiveness of an electrode array.

Larger fish, better able to swim against the current, can stay out of the electrical field, gradually working toward the bypass, and are then "guided" fish. Some smaller fish, unable to swim as well, drop downstream into the electrical field and pass through it, becoming "non-guided" fish. Fields, Adkins and Finger (5), reporting on the swimming ability of immature silver salmon, say that a difference in numbers swept out of a flume was due to size differences, the smaller fish being swept out sooner than larger fish.

Studies at the Central Valley Project in California included some tests of swimming ability of young salmon and striped bass. A "velocity endurance curve" was shown for these fish, demonstrating a linear increase in swimming speed with increase in standard length of the fish (10).

Water Velocity

Our preliminary laboratory trials with fry indicated that water velocity contributed to a lack of success in one phase of a field trial. The effect of water velocity has been noted by others. Holmes (7) refers to the critical nature of water velocity in his review of electric fish screens. Although he apparently was not able to obtain observations over a series of velocities, he quotes California Fish and Game representatives as stating that 0.5 foot per second is to be considered a maximum at which electricity can be used for screening downstream migrants. Brett, et al. (2), after measuring cruising speed of young sockeye and silver salmon, state in regard to the actual swimming rate, ". . . it is apparent that if approach velocities above dams exceed 1.0 ft. per sec. (30 cm./sec.) a real problem for safe-guarding underyearlings is presented."

The data of the present tests show the decrease in guiding effectiveness as the velocity increases (Table 2). It is apparent also that an increase in velocity caused a larger number of fish to move downstream, increasing the sample size. As larger numbers moved downstream in response to increased velocity, a greater proportion passed through the array. The decrease in effectiveness is significant and linear for all fish sizes combined (Table 3). The inverse effect of velocity is compared in Figure 2 with the effect of fish size.

In guiding tests using a light barrier at velocities from 0.35 to 3.336 feet per second, Fields, et al. (4) found an increasing number in the unguided portion as the velocity increased.

The findings made here with a limited range of velocities, the results of tests by Fields (5), and the remarks of Holmes (7) and of Brett (2) should not signify that guiding is impossible in streams of velocities higher than 0.5 to one foot per second. Rather it is suggested that it may be found profitable to maintain some control over velocity at sites chosen for installation of electrical (and other types of) guiding arrays.

Summary

The relationship of fish size and water velocity to the fish-guiding effectiveness of a single-row electrode array was tested under controlled laboratory conditions.

Three sizes of fingerling salmon were used: 59 mm, 80 mm and 105 mm mean total length. Also, three water velocities were used: 0.28 feet per second, 0.45 feet per second and 0.56 feet per second. Significant differences were found associated with each change in fish size and water velocity. Guiding effectiveness increased as the size of fish increased but decreased as the water velocity was increased. The relationship of each variable to guiding effectiveness was linear.

Acknowledgments

The stock of silver salmon fingerlings and the necessary fish food were provided by the Washington State Department of Fisheries through the cooperation of the Supervisor of Hatcheries, Mr. C. E. Ellis, and the personnel of the hatcheries at Issaquah and Toutle River.

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Proceedings of the Montana Academy of Sciences 19:91.

Preliminary Notes on the Vertebrate Faunas of the Montana Alpine

Robert S. Hoffman and Richard D. Taber

Abstract

Extensive work during the summer, 1958, indicates that, of the areas surveyed, the Beartooth Plateau has the most diverse fauna, including the following species: birds - *Lagopus leucurus*, *Anthus spinoletta*, *Eremophila alpestris*, *Salpinctes obsoletus*, *Leucosticte t. atrata*, *Zonotrichia leucophrys*; mammals - *Sorex vagrans*, *S. nanus*, *Marmota flaviventris*, *Citellus lateralis*, *Eutamias minimus*, *Thomys talpoides*, *Peromyscus maniculatus*, *Phenacomys intermedius*, *Clethrionomys gapperi*, *Microtus montanus*, *M. richardsoni*, *Ochotona princeps*, *Lepus townsendi*. In other alpine areas one or more of these species are lacking In Glacier Park, *Sorex nanus*, *Clethrionomys*, *Microtus montanus*, and *Lepus townsendi* are not known to occur in the alpine, and *Marmota flaviventris* is replaced by *M. caligata*. In the Big Belt and Crazy Mountains, *Lagopus*, *Sorex nanus*, *Microtus richardsoni*, and *Lepus townsendi* are apparently absent; in the Little Belts the absent species are *Lagopus*, *Sorex vagrans*, *Citellus lateralis*, and *Microtus richardsoni*. The most depauperate alpine fauna studied was on the Big Snowy Mountains, where *Lagopus*, *Eremophila*, *Leucosticte*, *Sorex* sp., *Marmota* sp., *Citellus lateralis*, *Phenacomys*, *Microtus* sp., and *Ochotona* were not found. In the Big and Little Belts, Crazies and Big Snowies, *Eutamias minimus* is replaced by *E. amoenus*. Only in the Little Belts and Big Snowies was *Microtus longicaudus* taken in the alpine.

Particularly noteworthy is a series of four *Leucosticte* taken in the Little Belts which are intermediate between *L. atrata* and *L. tephrocotis*, and the capture of two *Sorex nanus* on the Beartooth and one in the Little Belts. The latter is the first record for Montana.

This work was supported in part by National Science Foundation Grant No. 5174, and by the Montana Cooperative Wildlife Research Unit.

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P50

EARLY MORTALITY IN FUR SEALS ACCORDING TO SEX

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On the Pribilof Islands, Alaska, over 300,000 fur seals (*Callorhinus ursinus*) were tagged in the decade ending 1959. On the basis of preliminary studies (Kenyon, *et al.*, 1954), it was assumed that equal numbers of males and females were tagged. It was also assumed that the mortality rates of both sexes are equal up to age 3, at which time only 12 to 25 seals remain out of each 100 born. The data now accumulated from tag recoveries are not sufficient to prove or disprove that the mortality rates of the sexes are essentially equal up to age 3 or 4.

The writer has examined field data, mostly unpublished, obtained at sea off the west coast of North America and off Japan, and on the Pribilof Islands. The data pertain to 3,081 fetal seals taken at sea in January or later, 1952–59, and 3,648 black pups examined on land in August and September, 1950–59, within 3 months after birth. (Seals are born in greatest numbers in mid-July.)

A description of pelagic collecting methods has been given by Taylor, *et al.* (1955). The smallest fetuses available for study were taken in January. Although they had attained only ½ percent mean newborn weight, their sex was plainly shown by the presence or absence of a penial opening on the smooth surface of the belly. (Mean newborn weight for males is 5.4 kg. and for females is 4.8 kg. according to Scheffer and Wilke, 1953:133.) The sex of black pups on land in August and September was identified in four separate years during the course of routine studies on the Pribilof Islands by Fish and Wildlife Service biologists.

TABLE 1.—PRENATAL SEX RATIOS OF FUR SEALS, JANUARY–JULY[1]

10-day Period	Number of Fetuses			Percent Males
	Male	Female	Both	
11–20 January	1	–	1	100.0
21–30 January	32	54	86	37.2
31 January–9 February	162	143	305	53.1
10–19 February	108	106	214	50.5
20 February–1 March	129	130	259	49.8
2–11 March	75	75	150	50.0
12–21 March	114	119	233	48.9
22–31 March	73	67	140	52.1
1–10 April	112	102	214	52.3
11–20 April	113	94	207	54.6
21–30 April	152	143	295	51.5
1–10 May	139	143	282	49.3
11–20 May	67	56	123	54.5
21–30 May	124	106	230	53.9
31 May–9 June	27	24	51	44.3
10–19 June	62	59	121	51.2
20–29 June	50	65	115	43.5
30 June–9 July	19	19	38	50.0
10–19 July	9	8	17	52.9
Total	1,568	1,513	3,081	50.89

[1] 1952: 319 fetuses from American waters and 606 from Asian. From American waters: 1955, 97; 1958, 982; 1959, 1,077. The table has been compiled from data on original field-record cards.

The present study was conceived as a search for sex disparity in fetal death rates. While no disparity was found, the results are perhaps of general interest because they shed light on fetal sex ratios in a large, wild, relatively unexploited population of mammals. (While 3- and 4-year males are heavily exploited, fewer than 5 percent of the adult females are cropped annually.) Table 1 shows that the sex ratio of fetuses did not change appreciably throughout the last 6 months of gestation, mid-January to mid-July. Douglas G. Chapman, University of Washington statistical consultant, has applied a chi-square test of homogeneity to the data for individual 10-day periods, and has reported (*in lit.*) that they are "remarkably uniform." The 95 percent confidence limits for the overall percentage of males in the fetal population is 50.89± 1.79. The percentage of males in the five subsamples (footnote to Table 1) are, respectively, 53.1, 52.7, 40.2, 52.1, and 48.9. The subsample showing males in the minority, 40.2 percent, included only 97 seals.

Postnatal sex ratios are shown in Table 2. In each of four samples, males are in the majority.

In summary, the percent males in a sample of 3,081 prenatal seals was 50.9; in 3,648 postnatal, young seals, it was 52.4; in the combined lot of 6,729, it was 51.7. No shift in mortality rate by either sex was evident during the last 6 months of gestation.

TABLE 2.—POSTNATAL SEX RATIOS OF FUR SEALS, AUGUST–SEPTEMBER[1]

Year	Number of Pups			Percent Males
	Male	Female	Both	
1950	505	495	1,000	50.5
1957	653	547	1,200	54.4
1958	127	121	248	51.2
1959	626	574	1,200	52.2
Total	1,911	1,737	3,648	52.38

[1] Examined on Pribilof Islands.

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EXTRAIT DE MAMMALIA TOME 24 N° 3 Septembre 1960

NORTHERN FUR SEAL TWINS

by

K. NIGGOL and C. H. FISCUS jr.

U.S. Fish and Wildlife Service, Seattle

Les auteurs rapportent quatre cas d'embryons jumeaux de *Callorhinus ursinus*. Description et mensurations de ces embryons.

On several occasions on the Pribilof Islands, Alaska, observations have been made of one female fur seal *Callorhinus ursinus* nursing two pups. It has long been speculated that twinning must occur but escapes notice because of the difficulty of making observations on the crowded breeding grounds.

A 1923 record of twinning has generally been overlooked by zoologists (table 1). It appears as a footnote on page 136 in the annual report of « Alaska Fishery and Fur-Seal Industries in 1923 » (U. S. Bureau of Fisheries Doc. 973, 1925).

In 1958 and 1959, three sets of twins were collected during the course of pelagic fur-seal investigations conducted by the Fish and Wildlife Service. In the first set, both fetuses were in opposite uterine horns, and were of nearly identical size. In the second and third sets, each female carried one male and one female fetus in the left uterine horn. The male fetus was considerably larger, both in length and weight, than the female.

TABLE I

Record of twin fur-seal fetuses

Specimen and location	*Date*	*Estimated age (years) of gravid seal*	*Fetus*			
			sex	*lenght (cm.)*	*weight (kg.)*	*uterine horn*
....	10 May 1923	—	—	—	2.58	—
S. E. Alaska		—	—	—	0.85	—
U.S. 58-790	9 May 1958	11	F	54.0	3.49	L
Gulf of Alaska			F	53.0	3.43	R
U.S. 59-681	4 Feb. 1959	16	M	23.0	0.35	L
California			F	21.5	0.25	L
U.S. 59-1360	21 Feb. 1959	7	M	28.5	0.84	L
California			F	27.5	0.77	L

⁂

K. **Niggol** et C. H. **Fiscus**. — Occurrence de jumeaux chez *Callorhinus ursinus.*

Résumé

Records d'embryons jumeaux chez *C. ursinus :* 1 record en 1923 et 3 en 1958-59. Dans ces trois derniers cas les jumeaux étaient (1 cas) de même sexe et dans les cornes opposées et (2 cas) de sexe différent et dans la même corne de l'utérus.

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A Statistical Analysis of the Distribution of a Larval Nematode (*Anisakis* sp.) in the Musculature of Chum Salmon (*Oncorhynchus keta*-Walbaum)

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The pepsin-HCl digestion technique is probably the best method of isolating *Anisakis* larvae from the musculature of chum salmon. Some losses can be expected due to breakage of the resistant cuticle of *Anisakis*, and can be estimated to be about 6% when counting the parasites with the unaided eye.

Comparisons of *Anisakis* infections of the dorsal and ventral musculature indicated that very few larvae are found in the dorsal portions (above the lateral line). Forty-seven per cent of the fish had no dorsal infections, and 90% of the fish had less than 10% of total infection in the dorsal musculature.

Comparisons of *Anisakis* infection ratios of the right and left sides below the lateral line showed some variation. Chi-square tests of the hypothesis that 50% of the infections occur in either side indicated no significant differences. There were indications that large total infection intensities displayed less variation.

Comparisons of *Anisakis* infections of the anterior and posterior portions of the lateral musculature indicated that the infections were greater in the anterior portions. Calculated 95% confidence limits showed 50.0 to 59.0% infection in the anterior portion compared to 41.0 to 50.0% in the posterior portion.

Analyses of the *Anisakis* distributions within the anterior portions of the lateral musculature were hindered by extreme variation in the counts. In general, an average of 60% of the anterior portion infections occurred in the upper two quadrants of musculature, and 40% in the lower two quadrants. Changes in distributional patterns were affected by total parasite density, rather than by age or geographical location.

For purposes of comparing infection rates in chum salmon, distributional patterns indicate that the minimum sample of musculature which should be taken from each fish is one side below the lateral line.

The one factor which probably contributes the greatest effect on distributional patterns of *Anisakis* within chum salmon musculature is the total intensity of infection (or population density of *Anisakis*) in each fish.

Investigations of North Pacific salmon have included a study of the parasites of chum salmon as possible indices of the continental origin of Asian and North American stocks. Samples of chum salmon of known continental origin and samples of high seas catches were collected in 1955, 1956, and 1957. Over 30 species of metazoan parasites were recorded during the three sampling years. A larval nematode, *Anisakis* sp., showed some promise as an index of the continental origin of chum salmon.

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Briefly, larval nematodes of the genus *Anisakis* occur in the viscera and musculature of a number of marine fishes. Adult forms of *Anisakis* occur in marine mammals and sea birds. Salmon serve as intermediate hosts following the ingestion of infected planktonic invertebrate hosts. The larval *Anisakis* presumably penetrate the walls of the digestive tract and enter the coelom. Once in the coelom, they migrate through the peritoneal lining into the body musculature where they arrange themselves in tightly coiled lenticular cysts. It is reasonably certain that the larval nematodes persist in the musculature for at least a year and probably longer (Bishop and Margolis, 1955). Development within the musculature does not extend beyond the boring-tooth, larval stage; thus, the infection may be accumulative with the progression of time. Intensities of infection within age groups may vary from year to year due to changing ecological conditions during the marine residence of the salmon.

Preliminary examinations of samples of chum salmon musculature from the Asian and North American continents disclosed greater intensities of *Anisakis* infections in Asian stocks. It was theorized that statistical examinations of the quantitative intensities of infection within year classes might provide racial discriminates of high seas samples if Asian and North American criteria could be established.

Thus, the use of *Anisakis* as a racial discriminate of chum salmon was resolved to quantitative estimates of infection intensities, and it was necessary to establish uniform sampling and recovery techniques.

OBJECTIVE

Manual dissection of the musculature of whole fish for isolation of the parasites is time consuming, fatiguing, and subject to error. Stern *et al.* (1958) developed a procedure for isolation of *Anisakis* larvae by peptic digestion of the musculature. The procedure is rapid, comparatively simple, economical, and suitable for examination of large numbers of samples. The development of an expanded sampling program necessitated the investigation of additional methods for reducing time spent per sample.

The peptic digestion technique reduces the time and error involved in isolating the parasites from the musculature. Additional time could be saved if some particular portion of the musculature which displayed a consistent distribution of *Anisakis* could be utilized rather than the musculature in its entirety.

The distributions of *Anisakis* in the dorsal, ventral and lateral musculature were partially examined by Stern *et al.* (1958). Distributions of *Anisakis* in the anterior and posterior regions of the lateral musculature have been examined by the junior author.[3] The combined results of these experiments and the following series of experiments, which were designed to determine the distributions of *Anisakis* within the anterior portion of one side of the fish, were examined to evaluate:

1. The distributional patterns of *Anisakis* within the musculature;
2. The consistency of non-random distributions if they exist;
3. The potentiality of various portions of the musculature as indices of infection intensities.

METHODS AND MATERIALS

Division of the Lateral Musculature

The examination of *Anisakis* distributions in the whole left and right sides was completed prior to the incorporation of the digestion technique. Although manual dissection is not favored and subject to error, the samples of musculature examined for this experiment were thoroughly searched and it is believed that all of the larvae were recovered.

Division of the Dorsal and Ventral Musculature

Stern (op. cit.) chose the lateral line as a division between the dorsal and ventral musculature. Thus, the dorsal counts were taken from that portion of the musculature which lies above the lateral line, and the

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[3] Uzmann, J. R., and Lander, R. H. 1958. Progress report, Studies on parasites of chum salmon. Pacific Salmon Investigations, U. S. Fish and Wildlife Service, Seattle, Washington, October 1958. 10 p. Ditto process.

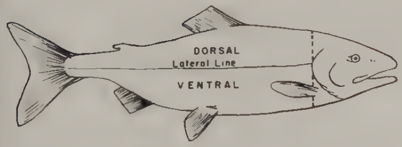

FIG. 1. The division of the whole musculature nto dorsal and ventral portions. The lateral line divides the two portions.

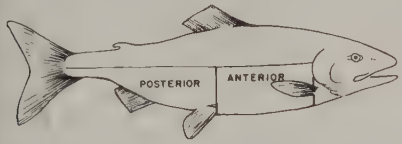

FIG. 2. The portions of musculature examined in the studies of *Anisakis* distributions within the lateral ventral musculature.

ventral counts from that portion which lies below the lateral line (Fig. 1).

Division of the Lateroventral Musculature

Uzmann (op. cit.) chose the anterior insertion of the pelvic fin as a division point between anterior and posterior portions of the lateral musculature below the lateral line (Fig. 2). In this experiment he chose either the right or the left side. The selection was based on the quality and condition of each side. The digestion method was used for isolation of *Anisakis* from the musculature.

Preparation of the Anterior Lateroventral Musculature Samples

The analyses of the distributions of *Anisakis* within the anterior fillet of the right side are based on the examination of 194 fish from two different geographical areas (Table I). The fish were numbered, measured, weighed, and sexed. Ages were determined from scale samples.

For this experiment, we selected a sample of the right ventral musculature, with definite topographical boundaries (shaded area—Fig. 3), as being the anterior sample of the musculature for all fish examined. Thus, each fish used was represented by a section of the musculature bounded dorsally by the lateral line, ventrally by the mid-line along the belly, anteriorly by the posterior insertion of the pectoral fin, posteriorly by the anterior insertion of the pelvic fin, and interiorly by the right side of the vertebral column. The samples were assigned the same identification number as the whole fish and refrozen until needed. The division of the sample into four quadrants is described in the *Digestion Procedure*, outlined below.

The natural resistance of the cuticle of *Anisakis* to pepsin-HCl proteolysis permits successful isolation of the parasites from the musculature under controlled conditions. Optimum conditions for peptic digestion can be maintained in a thermo-regulated water bath with motor-driven stirring paddles.

Digestion Procedure and Division of the Anterior Lateroventral Musculature into Four Quadrants

The hot water bath of the digestion apparatus was pre-heated and thermostatically adjusted for a temperature of 50–52°C. A pepsin-HCl solution was prepared of 2.5 g of 1:10,000 pepsin added to a solution 8.3–8.5 m of 12 N HCl in 1 liter of warm water.

The samples were removed from frozen storage and thawed in tepid water. Prewarming of the solution and flesh facilitates rapid digestion. Excess moisture was absorbed with paper towels and each sample was weighed to the nearest gram. The sub-

TABLE I

Samples Used in Quadrant Analyses

Year sampled	Area of collection	Age of fish	No. of samples	Area represented
1957	Ketchikan	4	50	S. E. Alaska
1957	Ketchikan	5	50	S. E. Alaska
1958	Skagit River	3	50	Puget Sound, Wash.
1958	Skagit River	4	44	Puget Sound, Wash.

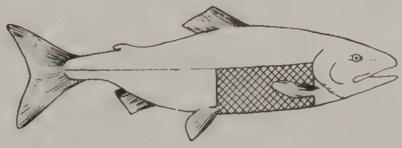

FIG. 3. The shaded area represents the sample taken from each fish for studies of *Anisakis* distributions within the anterior musculature.

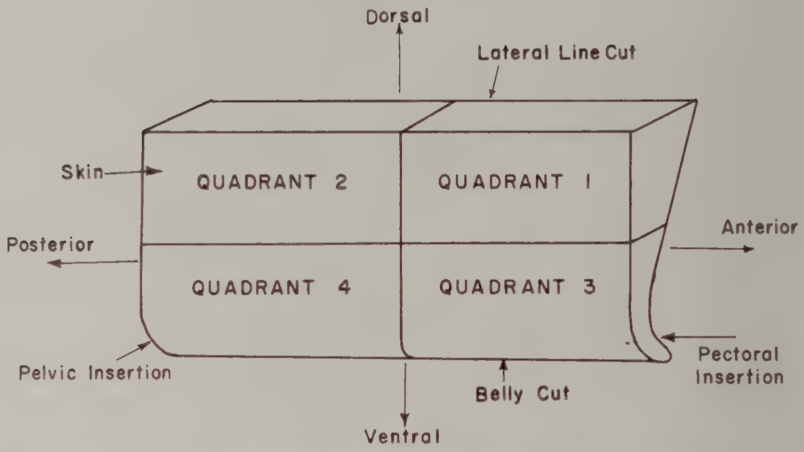

FIG. 4. Schematic drawing showing the position of the fillet in relation to the body and the equilateral quadrant relationships used in the studies of *Anisakis* distributions in the anterior portion of the ventral musculature.

peritoneal ribs were removed (the skin and bones are indigestible in pepsin-HCl), and each sample was cut into four quadrants by measuring the length and breadth along the skin-side surface, making each cut along the mid-point planes (Fig. 4). The skin was removed from each quadrant, and the flesh weight of each quadrant was recorded with previously obtained data.

The musculature of each quadrant was gently broken into smaller pieces and placed in individual glass beakers with an identification tag clamped to the rim (the quadrants were numbered by their relationships to other regions of the body). Five milliliters of pepsin-HCl solution per gram of flesh were added, and the beakers were placed in the hot water bath. The digestion apparatus used in these experiments (Fig. 5) holds eight 2-liter beakers or ten 1-liter beakers. The nylon agitators were run at moderate speeds (100–150 r.p.m.) for 45–55 minutes. The resultant mixtures were strained through a standard 80-mesh per square inch grading sieve. The sieve was washed several times to rinse away the fine suspension of digested flesh. Isolated parasites were transferred to a petri dish to which was added a 5–10% Formalin solution. When the dish was placed over a black background the parasites (which were usually tightly coiled) appeared opaque to white in color.

Counting Techniques

Each quadrant count was made twice. The first, or direct, count was made with the naked eye by one observer, counting only whole parasites or what appeared to be whole parasites. Fragments were not counted. The parasites (including all fragments) were transferred to labeled vials containing Formalin. The second or microscopic count was made by a different observer using a microscope and 60 magnification. The criterion established for enumeration by the microscopic technique was the presence of the head, including the labia. Thus, a fragment which might be composed of just the head with labia and a small portion of the pharyngeal region would be counted as a whole worm, while another fragment composed of the entire worm minus its head was not counted at all. Theoretically, this criterion would nullify the effects of fragmentation which might be found in nonmicroscopic enumerations, and present a true count which would be the standard for individual count comparisons, provided that no heads were lost during isolation and transfer.

Fragmentation Studies

Fragmentation studies were conducted on 50 three-year-old and 44 four-year-old chum salmon from the 1958 Skagit River late fall

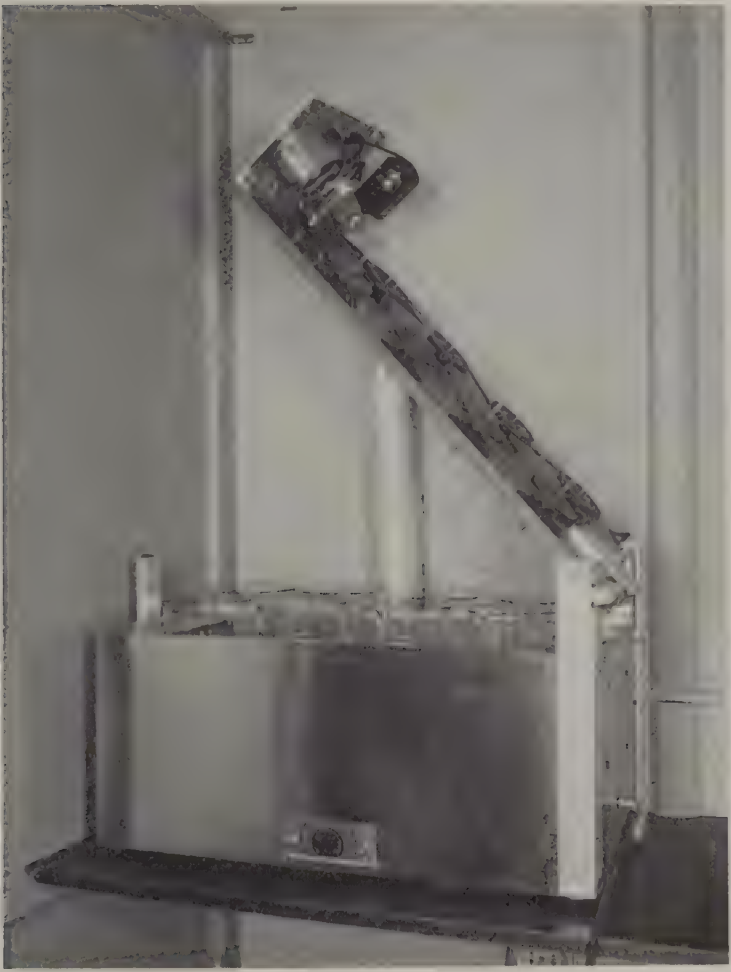

FIG. 5. Apparatus used for the isolation of *Anisakis* from the musculature

run as separate experiments to determine how parasite breakage affects the counts. These fish were taken in a commercial gill net at the mouth of the river in the late afternoon. The following morning they were placed in a cooler (−1°C ±1°C) at the laboratory. Samples of the anterior lateroventral musculature were taken during the next two days, tagged, and placed in frozen storage (−20°C). Prior to freezing, the largest percentage of *Anisakis* were probably still alive, although dormant, since they are known to withstand 0°C temperatures for over 72 hours in *Sebastodes* sp. and *Clupea pallasii* (Gustafson, 1953). Thus, these samples were subjected to only one freezing instead of two as in all other samples examined for this experiment. We believe that the *Anisakis* larvae extracted from these samples had less fragmentation and better appearance than any examined previously. Since both the fish and the parasites were in prime condition, the fragmentation in these samples should represent the minimal amounts which might be encountered in examination of other samples under present sampling programs.

When examined microscopically, all

worms and fragments were counted. If an entire worm were present, it was recorded on a standard form for individual fish-quadrant counts. If a head and some fraction of an attached body were observed, it was counted as a whole worm on the standard form and counted again on a separate tally sheet under the subheading "Heads without complete bodies." If a fragment was less than one-half of a full body coil, it was tallied under the subheading "Fragments." If a fragment had more than one-half of a full coil, but no head, it was tallied under the subheading "Bodies without heads."

ANALYSES OF ENUMERATION METHODOLOGY

Differences in Counting Techniques

A critical examination of the counting methodology was made in the experiments conducted on the four quadrant *Anisakis* distributions within the anterior musculature of the right side. Both methods involved counting of the same samples.

TABLE II

Changes in the Mean Counts of Anisakis *in the Quadrant Analyses by Logarithmic Transformations*

	Experiment number	Method A-eye B scope	Number of fish (n)	Quadrant number			
				1	2	3	4
Total *Anisakis* counts	1	A	50	174	158	80	53
		B		165	157	74	56
	2	A	50	215	227	134	144
		B		195	196	111	125
	3	A	50	103	92	84	51
		B		99	86	74	49
	4	A	44	199	148	113	136
		B		184	144	112	128
Modified mean *Anisakis* counts (Barnes method of transformation)	1	A	50	4.40	4.26	2.60	2.05
		B		4.32	4.09	2.47	2.06
	2	A	50	5.14	5.59	3.50	3.59
		B		4.86	4.98	3.30	3.26
	3	A	50	3.07	2.86	2.65	1.97
		B		2.99	2.74	2.44	2.06
	4	A	44	5.56	4.35	3.60	3.50
		B		5.18	4.24	3.52	3.33

Examination of data tabulated from *Anisakis* counts of over 1500 samples of anterolateral samples from widely scattered geographical locations has shown that *Anisakis* infections display a negative binomial distribution. Quantitative analysis of *Anisakis* in the case of stock discriminations of North Pacific chum salmon thus far has involved tests of mean counts. Any future studies of *Anisakis* infections in chum salmon by biological or technological services will, in all probability, be concerned mainly with mean counts. Therefore, it is appropriate to treat the two methods of enumeration as independent tests of the mean counts. Treatment of the mean counts still requires transformation, due to the negative binomial distribution. Since the standard deviation is roughly proportional to the mean, and large numbers of zero infections occur, the appropriate transformation is the logarithm of $(x + 1)$ (Barnes, 1952).

Table II indicates the typical changes of the mean counts after transforming back again by adding 1.15 times the transformed variance to the transformed mean before taking the anti-logarithm (Barnes, 1952). From the hypothesis that the difference of the transformed means of both methods is zero, t-tests at the 5% level (for n-2 degrees of freedom) show no difference in the two methods when tested for each of four quadrants for the four experiments.

Since the microscopic method consumes more time and requires additional equipment, it is evident that it is the least practical of the two for general analyses of *Anisakis* counts. The fragmentation studies of the Skagit River samples provide further evidence that this microscopic technique is impractical.

The Effects of Fragmentation

The criteria established for the fragmentation studies have been explained previously in the text. Table III shows the recorded counts of the two Skagit River samples examined.

It is obvious that a critical analysis of these counts is not axiomatic, or statistically reliable, but it is representative of the minimal fragmentation which could be expected

any chum salmon sample using the present
mpling techniques.

Our basic assumptions in analyzing the
gmentation of *Anisakis* were:

1. That the digestion technique would
late all of the larvae;

2. That some breakage would occur due
agitation of the solution;

3. That some portions of larvae with
oken cuticles would become lost during
e isolation and transfer processes.

The question of determining the effects of
ese possibilities and their relationships to
numeration methodology rests on an esti-
ate of the actual number of whole parasites
iginally present

Table III shows the total number of whole
orms in the three-year-old fish as 296.
dditional "fragments," etc., are present
nd represent a certain unknown number of
arasites which had lost partial body com-
onents during the isolation and transfer
rocesses. The smallest components, the
"fragments," could be from whole worms
which were broken up but not lost, or they
ould be parts of whole worms which were
ost. Since we had no way of telling which
ase they represented, we felt that including
hem in the treatment of the data was not
ustifiable.

TABLE III

Fragmentation of Anisakis *as Observed in 94 Samples of 1958 Skagit River Chum Salmon*

	Age 3	Age 4
Number of fish	50	44
Whole worms—by microscopic examination	296	535
"Heads without complete bodies"	12	32
Total count—by microscopic examination:	308	567
Total count—by direct observation:	330	596
Mean count—by microscopic examination:	6	13
Mean count—by direct observation:	7	14
"Bodies without heads"	52	93
"Fragments" (less than one-half full coil)	50	70

TABLE IV

Estimated Losses of Anisakis *Due to Fragmentation*

	Total number of *Anisakis* estimated to be present	Count by method	Discrepancy	Loss ratio in percent*
Experiment No. 1				
Age 3 fish				
Direct observation	348	330	18	5.2
Microscopic examination	348	308	40	11.5
Experiment No. 2				
Age 4 fish				
Direct observation	628	596	32	5.1
Microscopic examination	628	567	61	9.7

* Note the minor differences in the percentages of *Anisakis* missed between experiments for each method.

Although the "heads without bodies" cannot be definitely assigned to other body portions, it is not unreasonable to assume that they probably belonged to the "bodies without heads." Thus, for the 3-year-old fish, 12 additional parasites are accounted for, leaving 40 (52–12) bodies unaccounted for. These 40 "bodies without heads" must represent entire worms whose "heads" were lost during some phase of the laboratory procedures. For the 3-year-old fish then, we calculated 296 + 12 + 40 = 348, the total number of parasites estimated to be present, discounting the "fragments." Parallel estimates of total counts for the 4-year-old fish were made (Table IV).

The greater percentage of parasites missed by the microscopic examinations was sufficient evidence to establish the support of using the direct observation of "naked eye" counts in tabulation of the results of the four quadrant distribution patterns as well as providing a minimum "loss ratio" due to fragmentation.

ANALYSES AND RESULTS

Distributions of Anisakis *in the Dorsal and Ventral Musculature*

Templeman, Squires and Fleming (1957) examined the distributions of various nema-

TABLE V

Intensities of Infection of Anisakis *in the Dorsal and Ventral Portions of the Musculature (Revised from Stern et al., 1958)*

Dorsal *Anisakis* counts		Ventral *Anisakis* counts	Total counts
	0	3	3
	1	6	7
	2	6	8
	1	10	11
	0	12	12
	3	9	12
	0	13	13
	0	14	14
	0	14	14
	1	13	14
	1	13	14
	0	15	15
	0	15	15
	1	15	16
	1	17	18
	0	20	20
	1	20	21
	2	20	22
	2	20	22
	0	22	22
	0	24	24
	0	25	25
	1	25	26
	2	28	30
	0	30	30
	2	32	34
	3	35	38
	0	50	50
	0	53	53
	2	68	70
Totals	26	647	673
Means (N = 30)	0.9	21.6	22.4

todes in the musculature of cod, plaice and other ground fishes of the East Coast and concluded that the intensity of infection varied inversely as the distance from the coelom. Since nematode habits do not differ greatly, similar phenomena might be expected of *Anisakis* infections in salmon.

Stern *et al.* (1958) examined 30 chum salmon from scattered North Pacific sampling areas, using the digestion method. They chose the lateral line as the division point of the dorsal and ventral musculature. Less than 4 % of the mean number of par sites occurred in the dorsal musculatur with 95 % confidence limits ranging fro 1.3 % to 6.4 %. The percentages of dors infection for individual fish vary from ze to 25 %, but the extremely high percentag of dorsal infection occurred only in fish wit low total intensitities of infection (Table V

Figure 6 shows the distribution of t percentages of dorsal infection. Ninety pe cent of the fish had less than 10 % dorsal i fections. Forty-seven per cent of the fish ha no dorsal infections at all. The three fis which had dorsal infections greater than te percent had very low total infections. The appears to be only fractional increases i intensities of infection in the dorsal muscula ture when the total intensities increase (Fig 7), with no significance to the slope of th line. However, it is not known what th effects of extremely large total infectio intensities may be, and in certain Nort Pacific areas, total counts of between 10 and 1000 *Anisakis* have been observed an could be expected. If we assume that *Anisa kis* would take a path of least resistance,

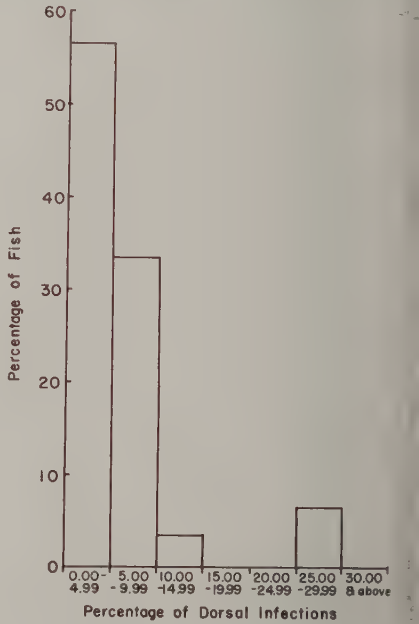

FIG. 6. The distribution of the percentages o *Anisakis* in the dorsal musculature from 30 chun salmon examined by Stern *et al.* (1958).

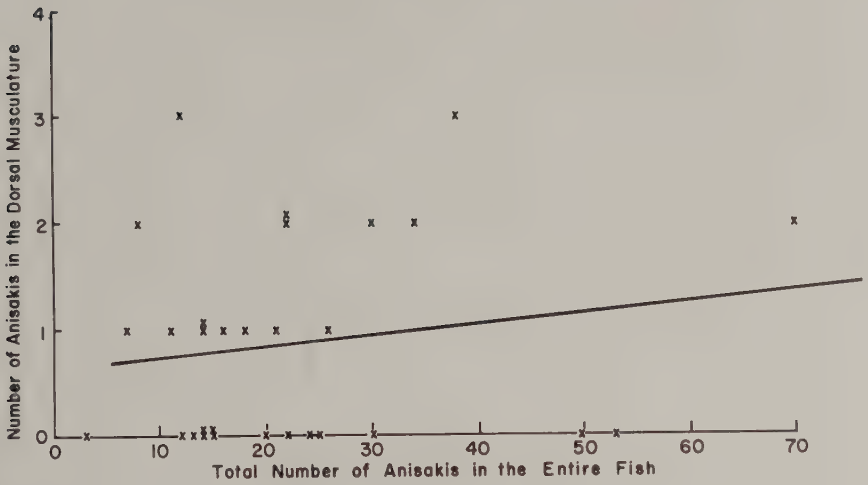

FIG. 7. Regression of the number of *Anisakis* larvae in the dorsal musculature (Y) on the total infection in the entire fish (X).

lesser intensity of infection might be expected in the dorsal musculature due to the natural barrier formed by the position of the vertebral column and its closely associated organs, such as the kidneys and swim bladder.

Distributions of Anisakis *in the Lateral Musculature*

Comparisons of whole left side and whole right side infections are based on data obtained from 27 samples of chum salmon taken in 1955 from five widely scattered North Pacific areas. Isolation of the parasites was by the dissection method.

An average of 47.6% of the parasites occurred in the right side and 52.4% in the left side (Table VI). A preliminary chi-square test of the left side[4] was made for the hypothesis that the side counts are independent of the total counts. The results of the test showed a probability (P) of independence greater than (>) 0.5 for 26 degrees of freedom (d.f.), which indicated that the total counts had no specific effect on the side counts.

Figure 8 shows the distributions of the percentages of *Anisakis* in the right and left sides. Note that there is considerable overlap in the ranges of 40% to 60% infection between both sides.

Ninety-five per cent confidence limits were calculated for each side. For the right side the limit is 0.47 ± 0.08 or 0.39 to 0.55, and the limit for the left side is 0.53 ± 0.08 or 0.45 to 0.61. This extended overlap in the 0.50 range suggests that there may be no significant difference in expected ratios of 0.50 for each side.

Chi-square was used to test the difference between individual fish distributions for the hypothesis that 50% of the parasites occur in either side. Samples 1, 2, and 3 were deleted in order to maintain expected values equal to or greater than ($\geqq$) 2.0 (Cochran, 1954). Of the 24 samples tested, 18 (or 75 %) had higher left side counts, which might suggest some preference by *Anisakis* for the left side. In order to examine thoroughly the possibilities of excess and defect, deviations with a common sign, and discrepancies between positive and negative deviations, the sum, pooled and interaction chi-squares were calculated.

	D.F.	Chi-Square	P
Sum	24	25.28	>0.250
Pooled	1	2.28	>0.100
Interaction	23	23.00	>0.250

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[4] Either side may be tested, since the side counts are complements of the total counts.

TABLE VI

Intensities of Infection of Anisakis *in the Right and Left Sides of the Musculature*

	Right side *Anisakis* counts	Left side *Anisakis* counts	Total counts
	1	0	1
	1	2	3
	3	1	4
	0	5	5
	2	4	6
	1	6	7
	4	4	8
	3	5	8
	4	5	9
	5	5	10
	10	1	11
	4	7	11
	8	7	15
	8	8	16
	8	9	17
	6	14	20
	9	15	24
	15	12	27
	17	20	37
	25	26	51
	27	31	58
	31	30	61
	30	32	62
	36	46	82
	58	61	119
	62	69	131
	103	104	207
Totals	481	529	1010
Means (N = 27)	17.8	19.6	37.4

We accepted the 1:1 ratio hypothesis on the basis of the three chi-square tests shown above. In the sum tests, of seven samples with total counts (N) equal to or less than ($\leqq$) 11, three contributed to the high value of chi-square. Only one contributed in the range $12 \leqq N \leqq 20$, and none where $N > 20$. Although 9 out of 11 samples where $N > 20$ had slightly higher left side counts, an additional chi-square test of the 1:1 ratio hypothesis for these 11 samples had a resulting chi-square with $P > 0.95$ for 11 d.f. This suggests that lightly infected fish will display random ratio distributions with wide ranges. As the total intensities of infection increase, the distributions of the individual fish ratios will more approximate the expected 1:1 ratio.

Distributions of Anisakis *within the Ventrolateral Musculature*

Comparisons of the anterior and posterior portions of the lateral ventral musculature were made from 36 samples representing widely scattered areas of the North Pacific. The digestion method was used to isolate *Anisakis* from the musculature.

Table VII shows the individual counts and percentages of infection for the anterior and posterior portions. Twenty-three out of 36 (63.9%) fish had higher counts in the anterior portion.

Figure 9 shows the distributions of the percentages of infection in both portions. Sixty-nine per cent of the anterior portions had percentages of infection in the range 40.0% to 69.9%. This indicates that there is a strong possibility of *Anisakis* preference for the anterior portion of the musculature, which seems reasonable in view of its proximity to the coelomic region.

Since we were interested in the consistency of the ratio distributions within the muscula-

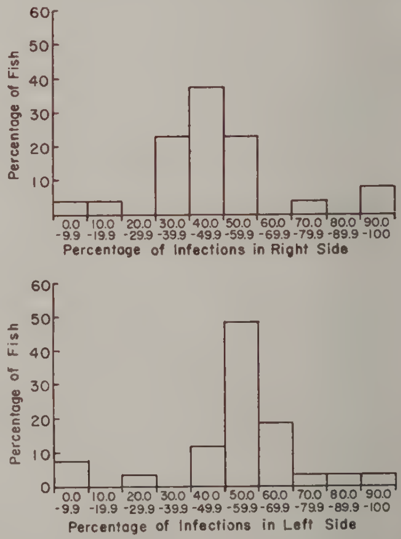

FIG. 8. The distributions of the percentages of *Anisakis* in the right and left sides of the musculature from 27 chum salmon

TABLE VII

ntensities of Infection of Anisakis *in the Anterior nd Posterior Portions of the Ventral Musculature of One Side of the Fish*

Anterior *Anisakis* counts	Posterior *Anisakis* counts	Total counts
11	3	14
6	9	15
8	7	15
5	13	18
7	13	20
7	15	22
12	11	23
13	11	24
14	11	25
17	9	26
13	15	28
16	13	29
18	11	29
20	11	31
22	9	31
14	17	31
23	9	32
12	20	32
30	8	38
26	12	38
20	19	39
29	10	39
24	16	40
22	19	41
19	28	47
22	27	49
20	29	49
30	19	49
40	17	57
33	24	57
23	36	59
39	23	62
41	22	63
42	36	78
35	45	80
93	102	195
Totals 826	699	1525
Means (N = 36) 22.94	19.42	42.36

ture, we began our examinations of *Anisakis* distributions in the anterior and posterior portions of one side of the musculature by testing the hypothesis that 50% of the infections in one side occurred in either portion. The sum, pooled and interaction chi-squares were calculated.

	D.F.	Chi-Square	P
Sum	36	95.78	<0.005
Pooled	1	10.58	<0.005
Interaction	35	85.28	<0.005

We therefore rejected the 1:1 ratio hypothesis on the basis of the three chi-square tests shown above.

We felt that the possibility existed that a closer approximation to a 1:1 ratio hypothesis between the two portions of individual samples might be present at higher density ranges. The samples were split into two groups: Group A (18 samples) of low density, with $N \overline{<} 32$, and Group B (18 samples) of higher density, with $N > 32$. A chi-square test of the 1:1 ratio hypothesis for Group A showed P for chi-square less than ($<$) 0.005 and for Group B showed P for chi-square < 0.005. Thus, we must reject the 1:1 ratio hypothesis.

We then examined the hypothesis that the ndividual infections approximate the mean

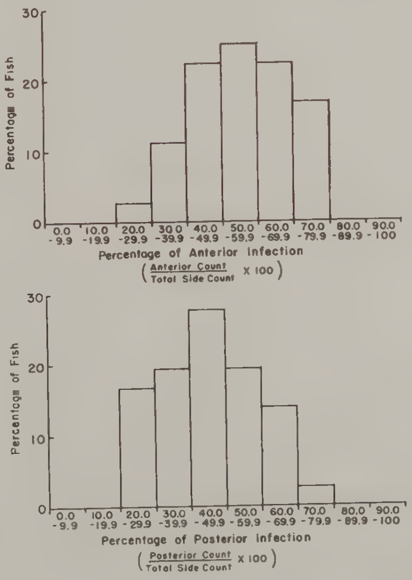

FIG. 9. The distributions of the percentages of *Anisakis* in the anterior and posterior portions of the lateral ventral musculature.

ratio of each portion for each density range. Here we found for Group A, which had a mean anterior portion infection ratio of 0.54, and a mean posterior portion infection ratio of 0.47, that P for chi-square < 0.010. For Group B, which had a mean anterior portion infection ratio of 0.55 and a mean posterior portion infection ratio of 0.46, we found that P for chi-square < 0.005. Thus, we must also reject the mean ratio hypothesis for the two density ranges. In this second hypothesis we have a closer approximation of what the expected ratios should be. If the differences between individual fish are so great as not to accept this hypothesis, then they are not likely to accept any other hypothetical ratios. For example, while the 95% confidence limits for the mean ratios of the anterior portions are 0.50 to 0.59, the probability of one anterior portion falling in this range is only 0.30.

Distributions of Anisakis *within the Anterior Sample*

The quadrant analyses. The general approach used in the previous analyses of *Anisakis* distributions within other portions of the musculature requires some modification in order to make comparative studies of the distributions within the anterior fillet or portion sample.

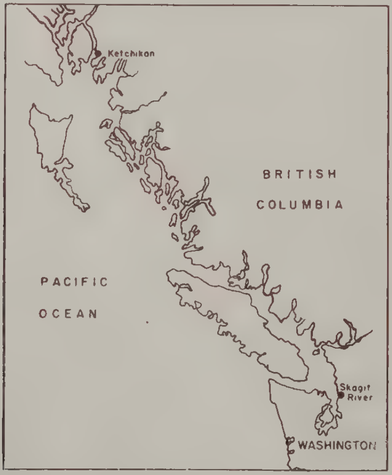

FIG. 10. Geographical locations from which samples were taken for anterior sample studies.

As the size of the musculature sampled is reduced, the quantities of parasites isolated are reduced. Although the areas from which the portion samples were taken are widely separated geographically (Fig. 10), the mean levels of infection for both areas are quite low, regardless of the age or size of the fish at maturity. Some of the anterior portion samples have zero infections for all four quadrants combined. It was felt that an anterior sample with a zero infection (regardless of what the infection in the remaining musculature might have been) could not be used in the analyses since the individual quadrant counts would be zero and thus would have no distributions to examine.

Analyses of *Anisakis* distributions of the larger portions of the musculature were comparisons of two independent structures; i.e., dorsal against ventral, left side against right side, etc. The percentage of infection of one portion was a direct complement of the other for any given fish. In the quadrant analyses, however, four separate components are being compared, rather than two. Thus, the percentages of infection in one or two quadrants may remain stable while the percentages of infection in the others may vary. For purposes of simplicity, quadrant infections used in the analyses of these four experiments are expressed as ratios; quadrant infection/total infection in the fillet. For example, quadrants 3 and 4 could maintain infection ratios of .25 each, while 1 and 2 vary from 0 to .50 each. Quadrant 4 (located in the posteroventral portion of the anterior portion sample) illustrates this phenomenon clearly. The graphs in Fig. 11, 12, 13, and 14 show the percentage distributions of the infection ratios for all four quadrants. While the first three quadrants exhibit distribution changes between ages and areas, quadrant 4 maintains a relatively stable slope. With the exception of quadrant 4, the distributional variation is extensive. Thus, the analysis of *Anisakis* distributions of the four quadrants resolves itself to two primary functions:

1. The differences between individual fish within groups;
2. The differences between groups of fish segregated by age and location at the time of capture.

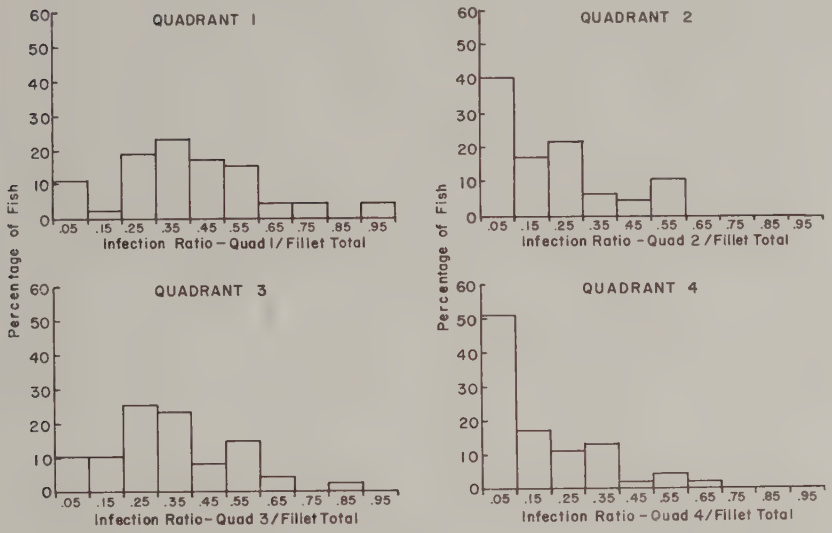

FIG. 11. Four quadrant experiment No. 1. 1957 Ketchikan 4-year-old chums. No. of fish = 47

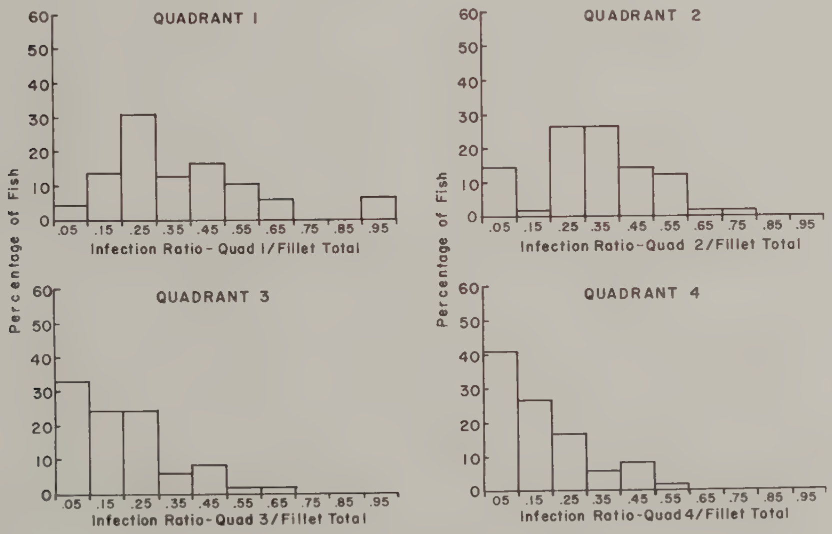

FIG. 12. Experiment No. 2. 1957 Ketchikan 5-year-old chums. No. of fish = 49

The intensity of infection is a related secondary function which must be taken into consideration when applying analytical methods.

We wished to use chi-square to test the homogeneity between individual fish infections for each quadrant; however, the low counts per quadrant presented problems of low expectance values. It is possible to compute tables when expected numbers are small (Haldane, 1939), but not without considerable effort. Cochran (1954) suggests grouping in such a way as to have expectance values > 2, and degrees of freedom < 30 in

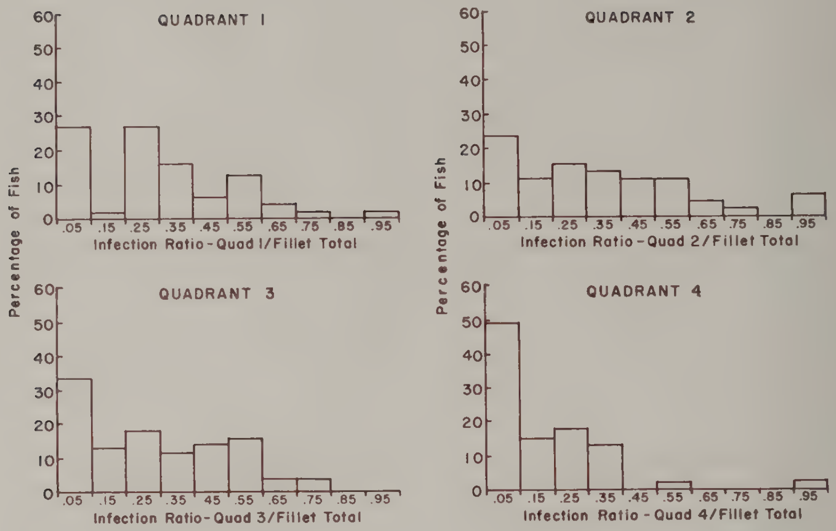

FIG. 13. Experiment No. 3. 1958 Skagit River 3-year-old chums. No. of fish = 45

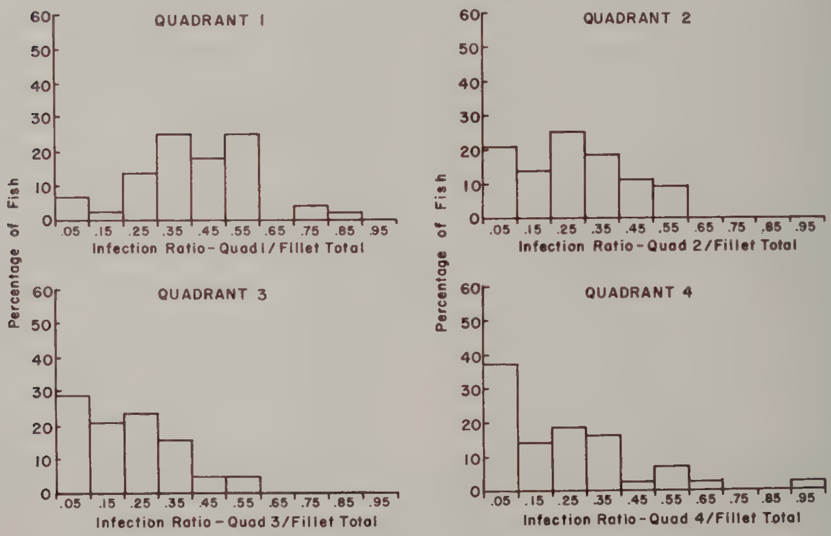

FIG. 14. Experiment No. 4. 1958 Skagit River 4-year-old chums. No. of fish = 43

order to maintain normal distributions of chi-square. In these experiments, grouping loses the sensitivity of chi-square in testing individual homogeneity, but gains the value of grouping by density in such a way as to test both the functions of individuality of small grouped samples and the density of infection.

The first chi-square tests were of fish grouped by densities within ages and areas. The fish within each density range were divided randomly and arranged in groups

TABLE VIII

Results of Chi-Square Tests of Homogeneity between Quadrants within Ages, Areas and Densities for Estimated Proportions of Infection

Code	Area	Experiment number	Age	Density range	Number of groups	Number of fish/group	Chi-square	d.f.	P	Estimated proportion Quadrant number 1	2	3	4
A	Ketchikan	1	4	$0 < n \leq 14$	10	4	25.6	27	>0.50	.36	.33	.16	.15
B	Ketchikan	1	4	$n \geq 15$	3	2	6.1	6	>0.25	.40	.35	.18	.07
C	Ketchikan	2	5	$0 < n \leq 9$	8	3	11.8	21	>0.90	.34	.29	.20	.17
D	Ketchikan	2	5	$10 \leq n \leq 14$	7	2	17.7	18	>0.25	.34	.38	.17	.11
E	Ketchikan	2	5	$n \geq 15$	11	1	31.8	30	>0.10	.27	.30	.19	.25
F	Skagit River	3	3	$0 \leq n \leq 10$	9	4	20.5	24	>0.50	.34	.31	.23	.12
G	Skagit River	3	3	$n \geq 11$	4	2	7.7	9	>0.50	.28	.24	.28	.20
H	Skagit River	4	4	$0 \leq n \leq 10$	9	3	31.3	24	>0.10	.43	.23	.16	.18
I	Skagit River	4	4	$11 \leq n \leq 26$	5	2	16.3	12	>0.10	.33	.26	.30	.11
J	Skagit River	4	4	$27 \leq n \leq 99$	6	1	15.9	15	>0.25	.30	.27	.19	.24

such that the expected number of parasites from the sum of each group was > 2, and that the number of groups within each density range did not exceed eleven in order to have thirty or less degrees of freedom.

The test was of the hypothesis that for each quadrant there is no difference between groups whose expected counts are based on the quadrant ratio means of that density range. Table VIII shows the results of the chi-square tests of this first hypothesis. The ratio means for each quadrant were carried out to five places (shown to two places in the table) and the expected values for each group were calculated from the quadrant ratio means for each density range. One sample in Experiment 4, Skagit River 4-year-olds with a total fillet count of 100, was dropped from the tests. We felt that this sample represented a separate, extremely high density range which did not fit in with the others. Chi-square tests of the remaining grouped samples all have values of $P >$ .10, for the various ratio means. The results of these first tests showed no significant differences. Thus, for grouped fish within these densities, ages, and areas, it is possible to make some prediction of the quadrant infections per group based on the mean ratio of infection for each quadrant within a given density range. The estimated proportions of infection for each quadrant for each density range varied considerably. However, quadrants 1 and 4 remained relatively stable in five out of the six low density ranges with mean infection ratios of 0.34 and 0.13, respectively. Since samples were combined into groups in eight out of the ten chi-square tests, homogeneity between individuals within ages and areas cannot be tested.

The second chi-square test was of the hypothesis that when calculated from the overall mean ratios for each quadrant, there is no difference in the estimated counts between ages, areas, or densities. To do this, we combined counts within density ranges (Table IX). The estimated proportions (or mean ratios) for each quadrant for all areas, ages, and densities combined were used to compute the expected quadrant counts for each density range. For the estimated proportions, the probability (P) that there is no difference in the estimated counts between ages, area, or densities is less ($<$) than 0.005 for 27 degrees of freedom. Thus, the second hypothesis does not hold true. However, $> 63\%$ of the contributions to chi-square $>$ 1.0 were attributed to the higher density ranges, a salient implication of the effect of density on group homogeneity.

To examine these implications, we developed two additional hypotheses, identical to the second except that we divided the densities and made two tests; one compared all ages, areas, and low densities to overall quadrant mean ratios for the low densities;

TABLE IX

Combined Counts within Density Ranges Used for the Chi-Square Test of Age, Area, and Densities vs. Quadrant Distributions

Code	Quadrant 1 Obs.	2 Obs.	3 Obs.	4 Obs.	Totals
A	98	91	45	41	275
B	67	59	31	12	169
C	49	42	28	24	143
D	55	61	27	18	161
E	111	125	78	102	416
F	60	54	41	21	176
G	40	34	40	29	143
H	65	35	25	28	153
I	53	42	48	17	160
J	63	57	39	50	209
	661	600	402	342	2,005
Estimated proportions (mean ratios)	0.33	0.30	0.20	0.17	

the other compared all ages, areas, and higher densities to overall quadrant mean ratios for the higher densities. Determination of the dividing point of low and higher densities was placed near 15. The groups from the previous tests were rearranged and separated into the two categories as shown in Table X. The two resulting chi-square tests based on the mean ratios of each category show $P < .005$ (for 12 degrees of freedom) for the higher densities, rejecting this hypothesis, and $P > .10$ (for 12 degrees of freedom) for the low densities, which is acceptable.

The conclusions which can be made from these last two tests are doubtful from the point of predictions of infections in the various quadrants due to the extreme variations encountered. However, we can conclude, with reasonable certainty, that density of infection can influence a sufficient number of individual distributions to the extent that they affect entire groups, more so than differences in age, or geographical origin of the fish samples.

The extreme variation of infections encountered in these quadrant studies leads us to believe that only weak generalizations can be made. From the data arranged in Table XI, we conclude that there is no strong

TABLE X

Combined Counts within Density Ranges Used for the Chi-Square Tests of Age, Area and High and Low Densities vs. Quadrant Distributions

	Code	Quadrant 1 Obs.	2 Obs.	3 Obs.	4 Obs.	Total
Low densities	A	98	91	45	41	275
	C	49	42	28	24	143
	D	55	61	27	18	161
	F	60	54	41	21	176
	H	65	35	25	28	153
	Totals	327	283	166	132	908
	Mean ratios	0.36	0.31	0.18	0.15	
High densities	B	67	59	31	12	169
	E	111	125	78	102	416
	G	40	34	40	29	143
	I	53	42	48	17	160
	J	63	57	39	50	209
	Totals	334	317	236	210	1,097
	Mean ratios	0.30	0.29	0.22	0.02	

TABLE XI

Mean Percentages of Anisakis *Infections in the Quadrants of the Anterior Portion Samples Grouped by Ages, Areas and Densities (coded)*

	Code	Mean percentage of infection Quadrants 1	2	1 & 2 comb.	3	4	3 & 4 comb.
Low densities	F	34.1	30.7	64.8	23.3	11.9	35.2
	A	35.6	33.1	68.7	16.4	14.9	31.3
	H	42.5	22.9	65.4	16.3	18.3	34.6
	C	34.3	29.4	63.7	19.6	16.8	36.4
	D	34.2	37.9	72.1	16.8	11.1	27.9
High densities	G	28.0	23.8	51.8	28.0	20.2	48.2
	I	33.1	26.2	59.3	30.0	10.6	40.6
	B	30.1	27.3	57.4	18.7	23.9	42.6
	E	26.7	30.0	56.7	18.8	24.5	43.3

ndication that the distributions of *Anisakis* are affected by age, or by the geographical area from which the samples came. However, there is a strong indication of distribution changes with changes in the total parasite population.

As the total number of parasites increases, the proportion of parasites in the upper and lower quadrants is more nearly equal. The factors affecting this change in distributions with increasing densities are not understood, since greater quantities of musculature appear in the upper two quadrants. As the total parasite density increases, then, the population of parasites per cubic unit of the lower two quadrants increases at a greater rate than that of the upper two quadrants.

Examinations of possible relationships between individual quadrant counts and physical characteristics of the fish, such as sex, length, body weight, and the weight of the flesh examined showed extreme variation. Thus, if any one particular factor contributes to the distributions of *Anisakis* in the quadrants, it appears to be the total population of *Anisakis* itself. Whether changes in the physicochemical character of the musculature become causative agents in the control of *Anisakis* distributions with increasing intensities is not known.

CONCLUSIONS

The information on *Anisakis* distributions given in this study is not complete nor sufficiently extensive to cover all situations which might be encountered. However, from the data examined to date, there are certain basic, useful conclusions concerning *Anisakis* distributions in chum salmon, which are:

1. From the samples of dorsal and ventral distributions, and the samples of lateral distributions which we have examined, there is no indication that changing distributions are a function of age or geographical location.
2. From the evidence available on the distributions within the various portions of the lateral musculature, there is no indication that distributional differences are caused by differences in age, geographical location, or morphological characters of the fish.
3. There is conclusive evidence that the distributions are affected by changes in the total intensity of infection. These conclusions are based on what we call low and higher infections, such as those used in the tests. It remains to be seen what effect extremely large infections have on distributional patterns.
4. If a sampling program were arranged which necessitated the examination and comparison of infection rates of individual fish, the variation of the parasite distributions within the musculature would require the examination of the entire musculature below the lateral line. The loss of parasites in the dorsal musculature would have little effect when making comparisons of individusl infection rates in chum salmon.
5. If a sampling program were arranged such that the samples could be grouped and comparisons of infection rates were based on mean counts, the distributional evidence indicates that examination of the musculature from one side below the lateral line would be sufficient. The group means for one side should closely approximate 50 percent of the group total infections in the musculature below the lateral line.
6. The use of samples of musculature smaller than one side below the lateral line appears to be extremely limited. The difficulties of accurate analysis of data from smaller samples whose distributions are affected by the parasite densities would warrant rejection of the use of such samples for comparative studies.
7. In general, the variation of the distributions within the musculature sampled becomes more extreme between individual fish as the size of the musculature sampled decreases, and must be given thorough consideration when comparative quantitative studies are to be made.

ACKNOWLEDGMENTS

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#53

USE OF FISH SCHOOL FOR CONDITIONED RESPONSE EXPERIMENTS

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A conditioned response experiment was carried out in January 1956 on the Pacific sardine, *Sardinops caerulea*, to assess the feasibility of applying such a technique to this and other clupeoid fishes in the study of their sensory capacities. The object was to determine (1) whether a school of sardines could be conditioned as a unit, and (2) whether the conditioned response of the school would be adversely affected by the replacement of mortalities with untrained specimens.

The experiment was conducted, as a part of the California Co-operative Oceanic Fisheries Investigations, by the Bureau of Commercial Fisheries Biological Laboratory at La Jolla. The staff of the public aquarium at Scripps Institution of Oceanography was most co-operative in providing space and facilities.

Methods

Twenty-one adult sardines, taken from a display aquarium containing three to four hundred sardines, were placed in a hexagonal concrete tank (46 × 27 × 49 × 15 × 49 × 27 inches and 30 inches deep) of 453 gallons capacity, which was supplied with a continuous flow of filtered sea water from an open pump and reservoir system. These fish had been established for some time in the display aquarium on high-protein food pellets, as recommended by the results of Farris (1956). The fish would swim rapidly through these pellets and pick them off individually as they dropped slowly through the water. No attempt was made to pick up any pellets that reached bottom.

To condition the experimental school, a five-foot length of board with a feeding port near the centre and a light suspended to one side of the feeding port was placed across a wide-angled corner of the aquarium. Another five-foot length of board, nailed at right angles to this baseboard, formed a vertical shield to hide all but the upper portion of the observer's face from the view of the fish. Violent movements were avoided, and at no time did the fish alter their behaviour when an observer appeared behind the shield. The light source, a six-inch tubular, 25-watt frosted bulb mounted so that the lower end projected below the surface of the water, was operated by a mercury switch located on the upper surface of the baseboard. Ambient illumination during the day was indirect sunlight from the windows of the building, none of which was immediately over the aquarium.

The school was subjected to twenty-one periods of conditioning over a space of twenty-two days, after which the aquarium was relinquished for another purpose. There were usually two periods of conditioning a day during the first half of the experiment and only one a day during the last half. The greatest interval between conditioning periods was 69 hours, from the morning of the thirteenth to the morning of the sixteenth. This was unavoidable, but fortunately it did not retard the progress of the experiment.

Each conditioning period consisted of ten trials carried out as follows: The light was turned on for five seconds. As it was switched off, about thirty premoistened food pellets were dropped through the feeding port. This food reached the bottom in six or seven seconds if not eaten. The light remained off for two minutes between trials, but as the experiment progressed it was sometimes necessary to lengthen the "light off" period to allow the feeding frenzy to subside. The light was switched on only when the fish were moving along the far side of the aquarium.

Dead or near-dead fish were removed from the aquarium after the conditioning period when they were discovered. No more than two such removals were ever replaced at one time with healthy specimens from the larger display aquarium. The presence of dead or near-dead fish in the aquarium during a conditioning period had no noticeable effect on the reactions of the other fish to the light and food.

After each trial the reactions of the fish to the light and to the food were recorded in some detail, and after the experiment was terminated, each of these entries was rated according to the following scale:

0. *No reaction to the light. No reaction to the food.* Sometimes the fish started slightly when the light went on or off.

Table I. Rated Response of Sardine School to Conditioned Stimulus. Each Conditioning Period Includes Ten Trials and is designated by a Date-Time Group. The rating scale is defined in the text. The letter notations indicate the following: *a* Outside disturbance, *b* Substandard food ration, *c* Food dropped during "light on", *d* Failure to record.

Periods (Date-Time)	Trials										Mean
	1	2	3	4	5	6	7	8	9	10	
041600	0	0	0	0	0	0	0	0	0	0	0
050930	0	0	1	1	0	0	1	0	1	1	·5
051600	0	1	1	2	2	2	2	2	2	2	1·6
060930	2	2	3	2	2	3	3	3	*a*	*a*	2·5
061615	2	2	3	3	2	2	3	3	0	3	2·3
071615	2	2	3	3	3	3	2	3	2	2	2·5
081615	3	4	4	4	3	3	2	3	3	4	3·3
090930	*b*	*b*	*b*	*b*	*b*	2	2	3	3	2	2·4
091615	1	2	2	3	2	2	3	2	4	4	2·5
100930	3	3	3	3	3	4	4	3	3	2	3·1
111100	2	4	4	4	4	4	4	4	4	4	3·8
121100	1	3	3	4	2	2	4	4	4	*a*	3·0
131145	1	2	3	3	4	3	4	3	2	*c*	2·8
160845	3	4	4	4	3	*d*	4	4	5	5	4·0
170945	3	5	5	5	6	6	6	6	6	6	5·4
181130	2	5	5	5	6	6	5	5	5	5	4·9
191130	3	4	5	5	5	5	6	5	6	6	5·0
201330	4	6	6	6	6	6	5	6	5	5	5·5
211500	2	5	5	5	5	6	6	5	6	5	5·0
230930	4	5	6	6	6	5	6	5	6	6	5·5
241100	2	5	5	6	5	6	6	5	6	6	5·2
251145	2	5	5	4	5	5	6	6	6	6	5·0

1. *No reaction to the light. Weak reaction to the food.* Less than one quarter of the fish noticed the food. Very few pellets were taken.

2. *No reaction to the light. Moderate reaction to the food.* Excitement was generated as soon as any of the fish detected the food, but many pellets were missed.

3. *Slight excitement during "light on" period. Strong reaction to the food.* Most of the food was taken.

4. *Moderate excitement during "light on" period. Instant reaction to the food.* There was a definite increase in the rate of swimming while the light was on. Virtually all of the food was taken.

5. *Strong allelomimetic* reaction during "light on" period. Instant reaction to the food.* The fish doubled or tripled speed and tightened up the school while the light was on. Virtually all of the food was taken.

6. *Strong allelomimetic turn towards the feeding port during "light on" period. Instant reaction to the food.* Sometimes the school made as many as three high speed circuits around the tank before the light was turned off. Occasionally there was evidence of confusion as they passed under the feeding port without receiving food. When the light went off they often shortened their circle to reach the feeding port. Virtually all of the food was taken.

Results

The response ratings for each trial are shown in Table I. The trials marked with letters were not given ratings because of outside disturbance or irregularities in the procedure, as described in the table heading. Fig. 1, in which the mean rating and first trial rating for each conditioning period are plotted against time, clearly illustrates the improvement in the conditioned response as the experiment progressed. It should be noted, however, that some degree of relearning was involved in every conditioning period. Response in the first trial was always lower than the average for the entire conditioning period, even though they both increase with time. In the earlier conditioning periods the response was not much better in the second and subsequent trials than in the first, but in the later periods response was almost invariably strong from the second trial on.

By the end of the experiment, 12 fish, or 4 per cent. of the 29 used, had died (Table II). The original school was composed of 21 fish, and

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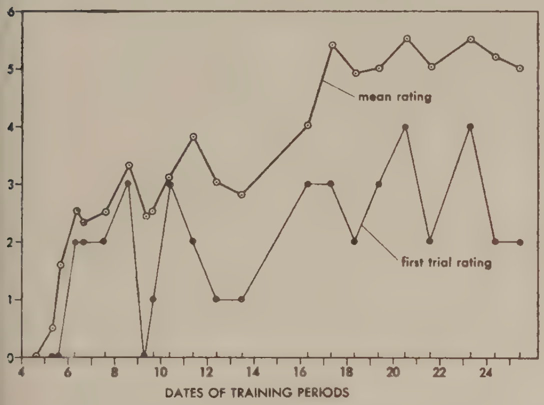
*Allelomimetry is a term used by Scott (1958) to denote "... behaviour in which two or more animals *do the same thing*, with some degree of mutual stimulation."



ig. 1. Curves of mean rating and first trial rating during e course of the experiment. The interval between dates presents twenty-four hours. Points are plotted at the aining period hour. See text for a n explanation of the sponse rating scale.

able II. A Record of Mortalities and Replacements during the Conditioning Experiment.

Date	7	11	16	19	20	24	Total
Mortalities	2	1	1	4	1	3	12
Replacements	2	1	0	2	1	2	8
Population	21	21	20	18	18	17	17

here were twelve deaths, eight of which were eplaced as they occurred. Failure to replace the ortality of the 16th was an oversight. Of the our removed on the 19th, two were dead and two moribund. Of the three removed on the 24th, two were dead and one moribund. Those that were removed after the 18th exhibited the symptoms attributed by Parrish, Blaxter & Holliday (1958) to epidermal damage and consequent disturbance of osmotic balance in herring.

Additions to the school during the course of the experiment, as given in Table II, did not have an noticeable effect on school response, as given in Table I and Fig. 1. As a matter of fact, each specimen added to the school was observed to act entirely in unison with the school from its first trial.

This experiment demonstrates that the conditioned response technique can be applied successfully to a small school of sardines, and that a moderate replacement of mortalities will not alter the conditioned response of the school. Since mortality in aquariums is a considerable problem with the Pacific sardine, the probability of carrying an experiment to fruitful completion would be much greater with a trained school than with one or a few trained specimens.

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Albacore Migration and Growth in the North Pacific Ocean as Estimated from Tag Recoveries

TAMIO OTSU

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Albacore Migration and Growth in the North Pacific Ocean as Estimated from Tag Recoveries

TAMIO OTSU[1]

THE ALBACORE, *Germo alalunga* (Bonnaterre), is considered a choice tuna by Americans because of its excellent canning quality. It is fished by Americans along the Pacific coast of the United States and by the Japanese in North Pacific waters extending from the coast of Japan to about the 180th meridian. In recent years the Japanese have extended their albacore fishing grounds to tropical and subtropical waters of the Pacific and Indian oceans (Mimura, 1957; Van Campen[2]), and more recently, to Atlantic waters.

A tagging program was instituted by the Pacific Oceanic Fishery Investigations (POFI) [in 1959 it became the Bureau of Commercial Fisheries, Hawaii Area] as a part of an albacore research project being conducted under Public Laws 329 (80th Congress) and 466 (Saltonstall–Kennedy Act, 83rd Congress). Employing the California type-G "spaghetti" tag (Wilson, 1953) (Fig. 1), and to a limited extent, the POFI- developed dart tag (Yamashita and Waldron, 1958), tagging was conducted on albacore taken by POFI vessels on exploratory cruises to the North Pacific. Intensive albacore tagging has been conducted on the West Coast by the California Department of Fish and Game and data on some of their recoveries have been published (Blunt, 1954; Ganssle and Clemens, 1953). This report summarizes the tagging results obtained by POFI, and includes a preliminary analysis of albacore migration and growth.

ACKNOWLEDGMENTS

The success of a tagging program depends largely on the cooperation of the fishermen making the recoveries, their interest in the program, and the care with which they record and transmit data pertinent to each recovery. We extend our gratitude to the numerous commercial fishermen and research agencies, both in the United States and in Japan, who have rendered excellent cooperation in this respect.

The writer is indebted to Dr. Robert H. Riffenburgh of the University of Hawaii for guidance in the growth analysis.

ALBACORE TAG RELEASES

Between January, 1954, and August, 1957, a total of 1,201 albacore was tagged and released in the temperate North Pacific (Fig. 2). Included in the total are 270 albacore tagged in the Japanese live-bait fishing grounds in the spring of 1956 (Van Campen and Murphy, 1957). The remaining tag releases were made in the central and eastern North Pacific, and consisted of 855 fish taken by surface trolling and 76 taken by long-lining.

The size-frequency distribution of the tagged albacore is given in Figure 3. The 270 fish tagged off Japan are not included since they were not measured. Measurements were made, however, on samples of fish from each school in which tagging was conducted, and these indicated a relatively narrow size range of 60.4 cm. to 83.4 cm. in length. In addition to these, 94 troll-caught fish tagged off the California coast are not included since no measurements were recorded. The long-line gear accounted for a wide size range of fish (50 to 120 cm.) while surface trolling took fish up to 87 cm. in length (Fig. 3).

ALBACORE TAG RECOVERIES

As of September, 1958, 15 (1.2 per cent) of POFI's tag releases had been recovered (Table 1). Seven of the recoveries (Nos. 1, 2, 3, 8, 9,

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[1] Fishery Research Biologist, Bureau of Commercial Fisheries, Biological Laboratory, Honolulu, Hawaii Manuscript received December 11, 1958.

[2] Van Campen, W. G. MS. The Japanese summer albacore fishery. Submitted for publication as a research report.

TABLE 1
POFI ALBACORE TAG RECOVERIES

NO.	DATE TAGGED	POSITION OF RELEASE		DATE RECAPTURED	POSITION OF RECAPTURE		NET DISTANCE TRAVELLED (miles)	DAYS OUT
		Latitude	Longitude		Latitude	Longitude		
1	10/4/54	46° 30′ N.	159° 18′ W.	11/28/55	35° 45′ N.	157° 39′ E.	2,055	420
2	10/5/54	43° 31′ N.	161° 16′ W.	1/19/56	35° 23′ N.	141° 20′ E.	2,670	471
3	10/9/55	42° 16′ N.	147° 16′ W.	6/24/56	31° 54′ N.	158° 37′ E.	2,660	259
4	10/17/55	44° 55′ N.	144° 48′ W.	8/1/56	31° 21′ N.	117° 17′ W.	1,515	288
5	7/31/56	44° 31′ N.	174° 55′ W.	7/23/57	30° 08′ N.	119° 03′ W.	2,775	357
6	8/1/57	34° 49′ N.	121° 57′ W.	9/17/57	34° 49′ N.	121° 26′ W.	26	47
7	7/22/57	35° 43′ N.	122° 58′ W.	10/7/57	36° 24′ N.	123° 07′ W.	41	77
8	10/16/55	43° 40′ N.	144° 40′ W.	11/23/57	33° 22′ N.	174° 07′ E.	2,025	769
9	11/17/56	36° 44′ N.	127° 37′ W.	11/17/57	38° 08′ N.	174° 53′ E.	2,800	365
10	7/23/57	42° 20′ N.	127° 33′ W.	5/26/58	32° 15′ N.	144° 15′ E.	4,230	287
11*	7/22/57	47° 00′ N.	126° 18′ W.	6/10/58	33° 40′ N.	144° 00′ E.	4,300	323
12	7/16/57	44° 47′ N.	130° 04′ W.	7/11/58	30° 00′ N.†	118° 45′ W.†	1,035	360
13	7/16/57	44° 47′ N.	130° 04′ W.	8/22/58	32° 00′ N.†	122° 00′ W.†	860	402
14	11/14/56	38° 00′ N.	128° 25′ W.	8/23/58	32° 15′ N.	122° 30′ W.	455	647
15	11/21/56	35° 21′ N.	123° 57′ W.	7/21/58	34° 00′ N.	122° 10′ W.	130	607

* Fish No. 11 was marked with a POFI dart tag; all others with California "spaghetti" tags.

† Approximate position of recapture.

10, 11) were made by the Japanese in their summer live-bait and winter long-line fisheries, while the remaining 8 were made by Americans in the West Coast fishery.

With the exception of two American recoveries (Nos. 6 and 7) which were made within 47 and 77 days, respectively, of the date of release, the remaining 13 represented relatively long periods between release and recovery, ranging from 259 to 769 days. While all of these long-term recoveries provided valuable information on the movements of albacore in the North Pacific, complete data on growth were not obtained since information on several of the recoveries did not include length or weight measurements.

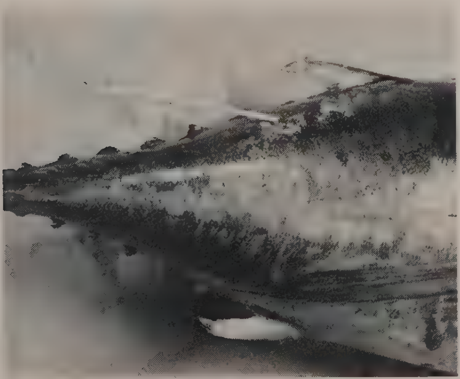

FIG. 1. An albacore (recovery No. 4) with a California type-G tag attached. This fish was at liberty for approximately 10 months before recapture (Table 1).

MOVEMENTS SHOWN BY TAGGED ALBACORE

The net movements of the tagged fish are depicted in Figure 4. Perhaps most significant is the migration of fish between the major fisheries. A fish tagged in the American fishery off California (No. 9) moved across into the Japanese mid-ocean winter long-line grounds to be retaken there. Two others tagged in the West Coast fishery off the Pacific northwest (Nos. 10, 11) made a complete trans-Pacific migration and were recaptured in the Japanese live-bait fishery. Albacore tagged in mid-ocean north of Hawaii migrated into the West Coast fishery (Nos. 4, 5) as well as into the Japanese longline (Nos. 1, 2, 8) and live-bait (No. 3) fisheries. Tag recoveries reported by the California Department of Fish and Game also showed movements of albacore from waters off California to the coast of Japan (Ganssle and Clemens, 1953). Movement in the opposite direction, from the Japanese fishery into the American fishery, has yet to be demonstrated.

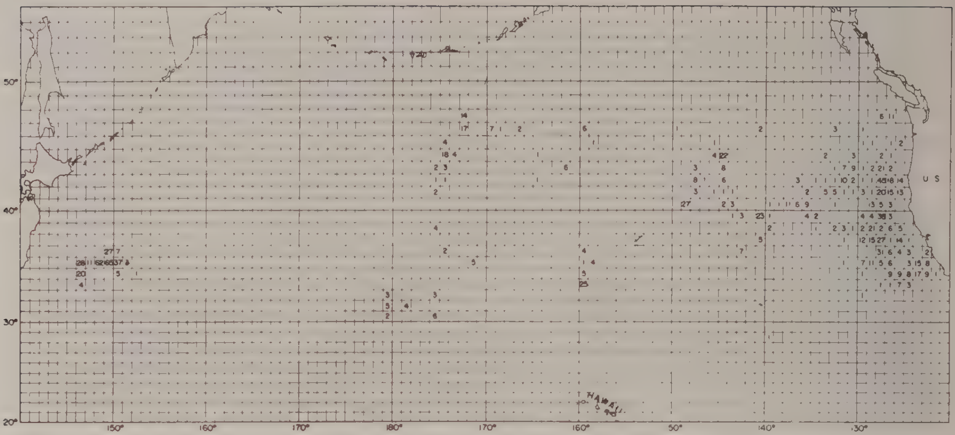

Fig. 2. Numbers and locations of POFI tag releases, January, 1954–August, 1957. (California type-G tag was used on 1,090, and the POFI dart tag on 111 albacore.)

GROWTH SHOWN BY THE TAGGED ALBACORE

Of 15 recoveries to date, 11 were accompanied by size data at the time of recovery (Table 2). The estimated annual growth of these fish was extremely variable, ranging from 3.8 to 28.7 cm. per year.

Although it is realized that the available data are inadequate for any conclusive growth study, a preliminary analysis was made in order to present some approximation of the albacore growth rate. Following the method of growth curve transformation described by Walford (1946), the length of fish at the time of release (age N) was plotted against the length after one year (age $N + 1$), the latter representing the length at release plus the estimated value of one year's growth (Fig. 5). There is a suggestion of linearity in the plots, with the exception of one (No. 2, Table 2). The growth reported for this fish is obviously out of proportion to the others. When the Japanese transmit data pertinent to a tag recovery they usually specify the method of measurement used. This was not done in this particular instance; for this reason and because the reported length seems excessive, this fish is dropped from further consideration. The remaining 12 points (including two from published California data) fall about the regression line $Y = 26.29 + .77867X$ obtained by the least squares method, where Y is the length at $N + 1$, and X the length at N.

Also shown in Figure 5 is the line of no growth ($L_N = L_{N+1}$) drawn in with a 45° slope through the origin. The point of intersection between the regression line and the line of no growth is described by Walford as the upper asymptote of the growth curve, which in this case falls at approximately 118 cm. The 118-cm. asymptote of maximum growth for the sample data of this paper is slightly less than that which would be expected for albacore populations in general; measurements of commercial landings indicate the population asymptote to be about 124 cm. (Suda, 1954; Otsu and Uchida, 1959*a*).

The growth curve (Fig. 6) was derived from Figure 5. This method does not enable us to obtain that portion of the growth curve falling below the point of inflection, and since the smallest fish for which there are data is a 60-cm. fish, the extrapolation toward the smaller sizes is dubious.

In an attempt to describe the complete growth curve, particularly that portion falling below the point of inflection, for which Walford's method does not apply, the data were fitted to a Gompertz equation, $y = ab^{c^{x+d}}$, where y is the length in centimeters and x the age in years. A

TABLE 2

GROWTH SHOWN BY TAGGED ALBACORE

NO.	DATE OF RELEASE	DATE OF RECOVERY	DAYS OUT	SIZE AT RELEASE (cm.)	SIZE AT RECOVERY (cm.)	NET GAIN (cm.)	GAIN PER YEAR (cm.)
1	10/4/54	11/28/55	420	78.2	—	—	—
2	10/5/54	1/19/56	471	68.0	105.0	37.0	28.7
3	10/9/55	6/24/56	259	63.4	—	—	—
4	10/17/55	8/1/56	288	59.9	72.3	12.4	15.7
5	7/31/56	7/23/57	357	68.4	78.0	9.6	9.8
6	8/1/57	9/17/57	47	66.5	—	—	—
7	7/22/57	10/7/57	77	65.5	67.0	1.5	7.1
8	10/16/55	11/23/57	769	65.1	94.8	29.7	14.1
9	11/17/56	11/17/57	365	85.2	97.5	12.3	12.3
10	7/23/57	5/26/58	287	78.0	85.2	7.2	9.2
11	7/22/57	6/10/58	323	75.0	—	—	—
12	7/16/57	7/11/58	360	65.0	77.3	12.3	12.5
13	7/16/57	8/22/58	402	75.0	84.5	9.5	8.6
14	11/14/56	8/23/58	647	79.4	92.6	13.2	7.4
15	11/21/56	7/21/58	607	68.6	86.4	17.8	10.7
A*	8/11/53	2/2/54	176	84.0	88.0	4.0	8.3
B*	8/16/53	2/23/54	192	91.0	93.0	2.0	3.8

* Fish tagged by the California Department of Fish and Game and reported by Blunt (1954).

rapid approximation method by Riffenburgh[3] for estimating the parameters of the Gompertz curve was used. The same paper contains a lengthier and more precise method in which the estimates converge stochastically to the parameters, but it was felt that the number of data available was inadequate to assure convergence. Thus, the approximation technique was utilized.

The method uses three sets of data points: (i, y_i), $(i+j, y_{i+j})$, and $(i+k, y_{i+k})$. The numerical calculation involved is markedly simplified if $k = 2j$. In this case, the triplet of points having x-values of $N + 3$, $N + 5$, and $N + 7$ (Fig. 6) was selected from among the set of triplets possessing the property $k = 2j$; these points fall approximately within the portion of the curve for which there are observed data. The corresponding y-values, obtained from Walford's curve, were $y_3 = 62.7$ cm., $y_5 = 84.8$ cm., and $y_7 = 98.2$ cm. The estimate of the parameter $c = 1.43$ was obtained by the equation:

$$c^{-j} = \frac{\log \dfrac{y_{i+k}}{y_{i+j}}}{\log \dfrac{y_{i+j}}{y_i}}$$

and the estimate of the parameter $b = 0.177$ by the equation:

$$\log b = \frac{\log \dfrac{y_{i+k}}{y_{i+j}}}{c^{-i}\, c^{-j}\, (c^{-j-1})}.$$

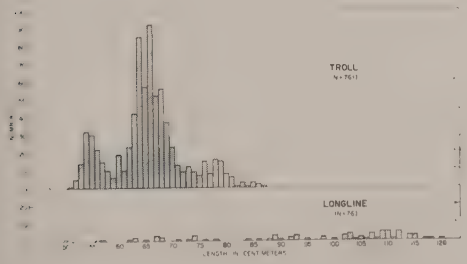

FIG. 3. Size-frequency distribution of albacore tagged by POFI in the North Pacific, January, 1954–August, 1957.

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[3] Riffenburgh, R. H. MS. A new method for estimating parameters of the Gompertz growth curve. University of Hawaii and Pacific Oceanic Fishery Investigation, U. S. Fish and Wildlife Service, Honolulu.

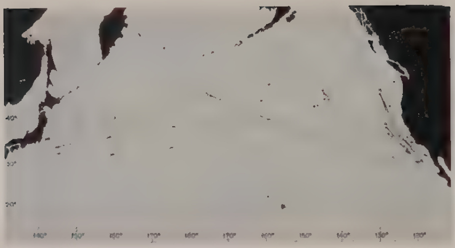

FIG. 4. Net movements of albacore tagged by POFI. (The lines have no significance other than connecting the points of release and recovery of each fish.)

The parameter *a*, or the upper asymptote of the growth curve (118 cm.), had already been estimated by Walford's method. These parameters were fitted into the Gompertz equation as follows:

$$y = (118)\ (0.177)^{(1.43)^{-x+d}}$$

which resulted in the asymmetric sigmoid curve shown in Figure 7. Inspection showed that if this curve is shifted 0.23 year to the right, it will present an adequate fit for the data; thus, an estimate of *d* is 0.23.

The curve derived by the Walford method (Fig. 6) is superimposed on the Gompertz curve. There is fair agreement between the two in the portions representing lengths between 40 and 85 cm., and the observed data do not deviate much from either curve. If albacore growth follows a typical Gompertz curve, then this represents a possible entire growth curve of the albacore, including that portion not possible to determine by the Walford method. It should now be possible to assign specific ages.

It can be seen by inspection that the curve approaches the abscissa reasonably closely at $N - 2$ years, suggesting that hatching is in this time vicinity. While the size indicated at hatching deviates from the expected size to the order of 2 cm., this error is not large considering the assumedly random deviations of the observed data from the estimated growth curve and the small sample size. With $N - 2$ as the arbitrary origin, the adjusted ages are given below the original designations. The resulting length for each year beginning with this origin is presented in Table 3 along with values obtained by the Walford method. While there is every indication that at least a portion of each curve reliably represents the albacore growth, those portions for which there are no observed data should be considered tentative. The initial growth by the Gompertz curve appears to be unreasonably slow since it requires about 3 years for a fish to attain a weight of 1 pound (about 30 cm.). The early growth is slow, relative to the result obtained by the Walford method. The results suggest a possible error in assigned ages of 1 or 2 years.

This disagreement and others may result from one or a combination of the following debilities: (a) the assumption that albacore growth follows the Gompertz curve may be unwarranted; (b) the number of observations may be inadequate; (c) there is the possibility that there is differential growth between the sexes after the onset of sexual maturity, causing an unbalanced sex ratio in favor of males among the larger albacore (Otsu and Uchida, 1959*b*). If this is true, then the growth curves are subject to inaccuracies in the upper portions representing fish larger than 90 cm., the approximate size at which the albacore is believed to attain sexual maturity. A differential growth rate may have been responsible for the slightly

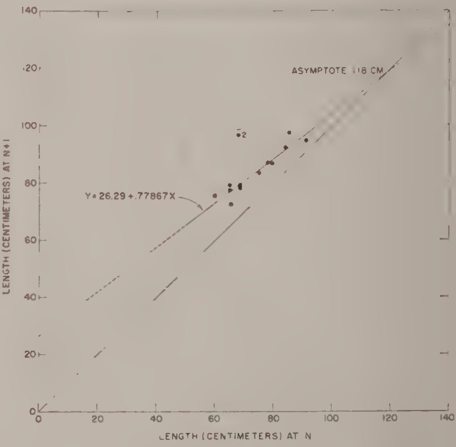

FIG. 5. Growth shown by tagged fish plotted by Walford's (1946) method and fitted with a straight line. The intersection of this line and the line $L_n = L_{n+1}$ indicates the upper asymptote of the albacore's length. Fish No. 2 was excluded from calculation of the regression line.

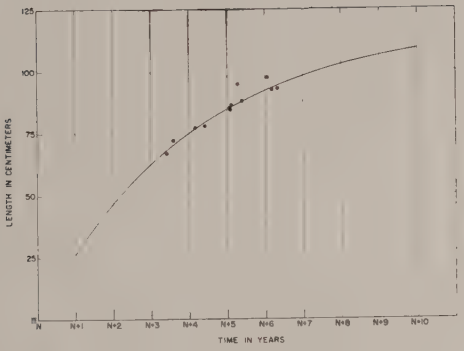

FIG. 6. Portion of growth curve of albacore obtained by Walford's method. Observed data are superimposed.

low estimate of the upper asymptote (Fig. 5) and for the deviation of the observed data from the upper portions of both curves (Figs. 6, 7).

Some studies have been made in the past on the age and growth of albacore, such as those by Uno (1936*a*; 1936*b*), Aikawa and Kato (1938), Partlo (1955), and Figueras (1955), all of which were based on the vertebral method of age estimation. Otsu and Uchida (1959*b*) also attempted to determine the age of albacore by this method and concluded in their study that the rings found on the centrum are probably not annuli as assumed by the several workers, but rather are growth marks laid down randomly with respect to time, and that, therefore, aging could not be accomplished by this method. In addition, they thought that the vertebral method generally yielded growth curves that were too linear to be typical and growth rates that were too slow when compared with the evidence from the then meager tag returns. The results of this study substantiate their criticisms.

The growth curves in question are compared with the curve obtained in this study (Fig. 8). Since the ages assigned in this paper (Fig. 7, Table 3) were arbitrarily defined, and since there are obvious discrepancies in the ages assigned by various workers, the mean lengths are plotted at yearly intervals without regard to the specific ages given. In other words, the curves in Figure 8 may be shifted freely in either direction along the abscissa. It is noted that the several growth rates do not differ markedly in magnitude.

It is clearly seen, however, that the presently derived curve, at least a portion of which is believed to be a fair representation of the actual albacore growth curve, is curvilinear, while the others, with the possible exception of Uno's (1936*b*) results, are almost perfectly linear. This difference in curvature supports the contention that the age of albacore could not be determined by the vertebral method. The linearity suggests that the rings found on the vertebrae are associated with growth rather than with age, and that ring formation is a linear function of fish growth.

Aside from growth studies by the vertebral

TABLE 3

GROWTH RATES OF ALBACORE DERIVED BY FITTING TAG RECOVERY DATA TO GROWTH CURVES BY THE METHODS OF WALFORD AND RIFFENBURGH

AGE* (years)	LENGTH (cm.)	
	Walford	Riffenburgh
1	—	7.5
2	—	17.3
3	26.3	31.5
4	46.8	46.5
5	62.7	62.5
6	75.1	75.0
7	84.8	86.0
8	92.3	94.5
9	98.2	101.0
10	102.7	106.0

* The ages given are based on an arbitrarily selected origin (Fig. 7) and are therefore tentative.

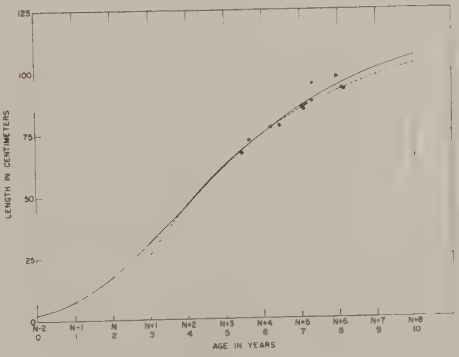

FIG. 7. Growth data fitted to a Gompertz equation by Riffenburgh's short method. The curve obtained by Walford's method (dashed) is superimposed. Observed data are superimposed on the Gompertz curve.

method, several workers have analyzed albacore size frequencies. Brock (1943) found two regularly occurring modal groups in the California length frequencies for the years 1924 to 1928 inclusive. The consistency in the appearance of these groups indicated that they were year classes. A more uniform relation was seen in the "lagged difference," or the difference in the modal size of group A in 1 year with that of group B in the following year, rather than between the two modal groups of the same year. The modal lengths (lagged) of both California and Oregon albacore are reproduced in Table 4.

The lagged modal values for the California albacore fall in nearly perfect agreement with the growth shown by the tagged fish, indicating that the distinctly bimodal distribution represents two age groups, one a year older than the other, as postulated by Brock. The growth of the Oregon albacore, on the other hand, was somewhat less than that estimated for the California albacore, and consequently lower than the growth shown by the tagged fish.

Suda (1954) has examined the size distribution of albacore taken in the Japanese winter long-line season and has traced six different size groups which appear yearly. The modes of these groups were: 57 cm., 67 cm., 78 cm., 89 cm., 100 cm., and 111 cm. The spacing of the intervals is uniformly 10 or 11 cm., thus representing a straight-line growth if these length groups are assumed to be age classes. The author concluded that these length groups may be considered as age groups if they are handled as five groups consisting of ages I to IV and an advanced age group which includes the last two modal groups. If these modal lengths are compared with the results obtained from tagging, it is seen that as in the case of the results obtained by the vertebral method, the yearly growth increments do not differ greatly, but there is a marked difference in the curvatures of the two curves. Suda pointed out that since growth of most living organisms is logistic, it may be unreasonable to postulate these length groups as age groups. However, he advanced the possibility that these age groups fall within the relatively straight portion of the growth curve. This is not indicated by the data presented in this paper.

TABLE 4

Modal Lengths of California and Oregon Albacore, in Centimeters

(Reproduced from Table 7, Brock, 1943)

GROUP A	GROUP B	DIFFERENCE
CALIFORNIA ALBACORE (1924 to 1928)		
1924, 64.89	1925, 77.18	12.29
1925, 64.87	1926, 77.16	13.29
1926, 68.84	1927, 81.04	12.20
1927, 65.80	1928, 78.27	12.47
OREGON ALBACORE (1938 to 1940)		
1938, 66.18*	1939, 74.19	8.01
1939, 64.02	1940, 74.26	10.24

* Only a single small sample was taken in 1938 after the season was underway.

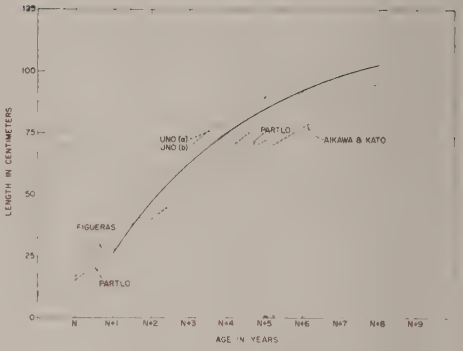

Fig. 8. A comparison of the growth curves obtained by the vertebral method with the Walford curve obtained in this study. Specific ages are disregarded in the plotting of these curves.

DISCUSSION

The tag recoveries have shown that albacore migrate considerable distances, and from one fishery to another, suggesting that there is a single population of albacore in the temperate North Pacific, exploited seasonally by Americans off the West Coast during the summer and fall, by the Japanese in mid-ocean during the winter, and also by the Japanese in the western Pacific during the spring and summer.

While no recoveries of albacore tagged off Japan have yet been reported in the American fishery, there are suggestions of movements in that direction. For example, recoveries 11 and 12 were of fish tagged within a week of each other in waters of the American fishery off the Pacific northwest. One was recaptured in June, 1958, in the Japanese live-bait fishery, and the other, a month later in the American fishery. The suggestion is that the latter had also undergone an extensive migration to the west before returning to the American fishery, although this movement may not have been as complete as the other. A similar suggestion is made by the recapture in the American fishery after 306 days of an albacore tagged by the California Department of Fish and Game. One other albacore, tagged at the same time, had been recaptured a month earlier 145 miles east of Tokyo, Japan (Anonymous, 1957). An appreciable tagging program by the Japanese may show definitely whether or not there is a movement of fish from the Japanese live-bait fishery into the American fishery.

However, judging by the sizes of fish generally taken in the different fisheries, it is possible that even extensive tagging by the Japanese would not confirm such a movement towards the east. The chances for American recovery of Japanese-tagged fish are not good unless the Japanese tag unusually small fish or unless unusually large fish move into the American fishery in large numbers. The sizes of fish commonly taken in the respective fisheries are shown in Figure 9. The American West Coast fishery generally takes smaller albacore than either the Japanese live-bait fishery or their long-line fishery; the fish range in size from about 50 to 85 cm. with the predominant sizes around 65 cm. The bulk of the fish taken by the Japanese is larger than 70 cm. in length, and these sizes comprise only a very small part of the American landings. On the other hand, small albacore under 70 cm. may be present in larger numbers in the Japanese live-bait fishery than indicated in Figure 9. Suda (1955) states that such small fish constitute a significant portion of the landings during certain years. The chances for recovery would seemingly be improved if tagging is concentrated on such small fish.

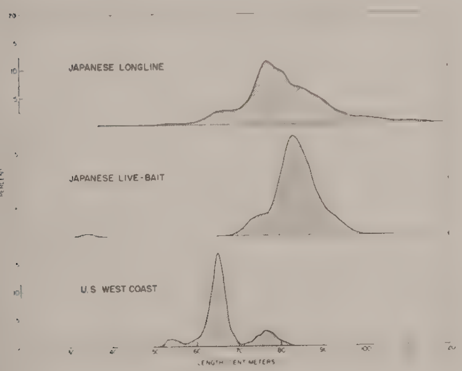

FIG. 9. Examples of albacore sizes taken by the major North Pacific fisheries. The Japanese size-frequencies were obtained from Nankai Regional Fisheries Research Laboratory (1951). The West Coast length frequency is based on unpublished data of the Oregon Fish Commission and are measurements made on albacore landed in Oregon during the 1957 season.

Although there appears to be little chance for fish tagged in the western Pacific to be recovered in the American fishery, a large-scale tagging program by the Japanese stands to serve an equally important purpose, that of elucidating the relationship between the albacore of the temperate and tropical Pacific Ocean. There is at present no direct knowledge concerning the movements of the larger albacore. The larger fish of the temperate North Pacific appear to move south into tropical and subtropical waters, perhaps to form the reproductive segment of the population. If there is such a southward migration of the larger fish, this may be shown someday by the recovery of a tagged fish. With Japanese vessels exploiting wide areas in the tropical Pacific, chances for recovery of fish tagged in the north should be favorable.

With respect to the growth curve obtained in this study, there are certain implications which merit brief consideration. If the Gompertz curve (Fig. 7) is a true representation of albacore growth, then the following points may be made: (a) the albacore is a relatively slow-growing tuna; (b) this species has a relatively long life span. Furthermore, as mentioned, it is believed that an albacore attains sexual maturity at a length of about 90 cm. If this is so, then it requires between 7 and 8 years for an albacore to become sexually mature. This is a significant portion of the life span. Since albacore enter the fisheries in substantial numbers at around 50 cm. in length (Fig. 9), a year-class is thus exploited for about 4 years before it even attains maturity.

SUMMARY

Of 1,201 albacore tagged in the temperate North Pacific Ocean by POFI between January, 1954, and August, 1957, 15 recoveries (1.2 per cent) were reported. These recoveries indicate considerable movement of fish in the North Pacific. Albacore tagged in mid-ocean north of Hawaii have been retaken in the American West Coast fishery as well as in the Japanese fisheries. Certain recoveries were of fish which migrated across the Pacific from the American West Coast to the vicinity of Japan. There is indication that Americans and the Japanese are exploiting the same population of albacore in the temperate North Pacific Ocean.

The data on growth, although insufficient for a conclusive study, were subjected to a preliminary analysis by Walford's method of growth curve transformation, and the resulting data were also fitted in a Gompertz equation. The derived growth curves are presented.

At least those portions of the growth curves for which there are observed data appear to be a reliable representation of albacore growth. These curves are curvilinear, contrary to several linear albacore growth curves reported in the past by workers who based their studies mainly on the vertebral method. The linearity of the latter curves suggests that the age of albacore cannot be determined by the vertebral method; the rings on the centra are probably directly associated with growth rather than with age.

The results indicate that the albacore is a relatively slow-growing tuna with a rather long life span. A significant portion of the life span is passed in the immature state.

Although POFI in cooperation with the Japanese has tagged 270 albacore in the Japanese live-bait fishery, and the Japanese have recently started a tagging program in the western Pacific, none of these fish has been recovered in the American fishery. In view of the fact that the Japanese exploit generally larger albacore than the Americans, the chances for recovery in the American fishery of Japanese-tagged albacore are far less than for Japanese recovery of American-tagged fish.

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A HIGH INCIDENCE OF THE HYBRID *ACROCHEILUS ALUTACEUM* × *PTYCHOCHEILUS OREGONENSE*.—In 1957 and 1958, 19 hybrid cyprinids of the parentage, chiselmouth, *Acrocheilus alutaceum,* × squawfish, *Ptychocheilus oregonense,* were collected in the Yakima River, Washington State, by the U. S. Fish and Wildlife resident fish studies staff, Seattle Biological Station, Bureau of Commercial Fisheries. Eight of these were taken in the Prosser power diversion ditch by-pass trap near Prosser, Washington, on October 15–16, 1958. The other 11 were discovered in electro-fishing collections from the Yakima River during 1957 and 1958.

The chiselmouth × squawfish hybrid is not common, as determined by extensive electro-fishing throughout the Yakima River. Completed data on these collections show 11 hybrids of this parentage out of a total of 23,400 fish, of which 4,260 were chiselmouth and 2,000 squawfish. The high occurrence of the hybrid at the Prosser fish trap warrants reporting.

Previous descriptions of this hybrid were made from two individuals, one taken in the Willamette River near Corvallis, Oregon (Snyder *Bull. U. S. Bur. of Fisheries, 27(1907):153–189,* 1905) and the other from a tributary to the Snake River near King Hill, Idaho (Hubbs and Schultz, *Occ. Papers Mus. Zool. Univ. Mich. (232):1–6,* 1931). To corroborate the identification of the chiselmouth × squawfish hybrid and to extend knowledge about this hybrid, data from the Yakima River specimens are included.

Prosser trap collection: Eight hybrids were collected in an inclined-screen fish trap, installed to collect fishes by-passed back to the Yakima River from the Prosser power-diversion ditch. The trap was in operation for two successive days to collect scrapfish for laboratory experiments. Fish movement into the trap was almost entirely at night and is indicative of a downstream migration. Scale examination of a five-fish sample of the hybrids with a range of 185 to 205 mm. fork length indicated them to be fish that had lived two winters.

Four species of fishes and a crayfish were trapped with the hybrid. There was a heavy downstream movement of largescale suckers, *Catostomus macrocheilus,* all approximately 200 mm. long. Other incidental fishes were chiselmouth, largemouth bass, *Micropterus salmoides,* and the brown bullhead, *Ictalurus nebulosus.* About one-half of the trapped fishes were released without examination. Upwards of 4,000

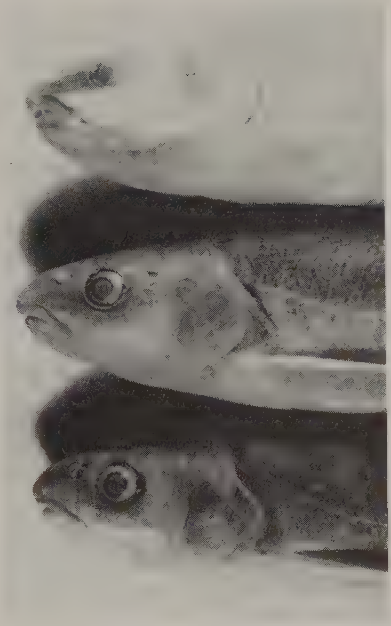

Fig. 1.—Three chiselmouth (*Acrocheilus alutaceum*) X squawfish (*Ptychocheilus oregonense*) hybrids, showing the characteristic head and mouth.

TABLE I

COMPARISON OF DIAGNOSTIC CHARACTERS OF THE CHISELMOUTH (*Achocheilus alutaceum*) × SQUAWFISH (*Ptychocheilus oregonense*), ITS PARENTS AND THE REDSIDE DACE (*Richardsonius balteatus*)

Characters	Species			
	Ptychocheilus	Hybrids	*Acrocheilus*	*Richardsonius*
Number examined	14	14	10	9
Rays in dorsal fin				
Range	10	10–11	11	10–12
Average	10	10.8	11	10.7
Rays in anal fin				
Range	9–10	9–10	10	14–17
Average	9.9	9.8	10	15.7
Vertebrae				
Range	44–46	43–46	45–48	41–42
Average	45.2	44.9	46	41.7
Scales in lateral line				
Range	69–76	75–86	86–94	55–63
Average	71.9	80.2	90.3	58.2
Scales above lateral line				
Range	14–19	15–22	21–27	11–13
Average	16.1	18.4	23	12
Scales below lateral line				
Range	8–12	8–15	13–16	6–9
Average	10	10.8	13.9	7.1

crayfish, *Pacifastacus klamathensis*, also moved into the trap during one night.

Electro-fishing collection: Eleven hybrids were discovered among electro-fishing collections from the Yakima River. The hybrids were taken at various locations between the mouth and the town of Yakima, 100 miles upstream. The size range of these fishes is 70–287 mm. fork length.

Verification of hybridization: The squawfish and chiselmouth are considered the parents because of the intermediate characteristics of the hybrid to these fishes (Fig. 1) and lack of resemblance to other possible cyprinid parents in the Yakima system. The Yakima cyprinids include carp, *Cyprinus carpio*, peamouth chub, *Mylocheilus caurinum*, chiselmouth chub, squawfish, Columbia redside shiner, *Richardsonius balteatus*, longnose dace, *Rhinichthys cataractae*, Columbia River dace, *R. falcatus*, and speckled dace, *R. osculus*. The peamouth is rare in the Yakima system and offer little chance of hybridization. The three daces are small and do not occupy the same habitat as adult squawfish and chiselmouth. Carp are not known to hybridize with indigenous cyprinids. Redside shiners do not resemble the hybrids in most characters (Table I).

Meristic counts from a sample of the suspected parent species from the Yakima River are compared with the hybrids from electrofishing and Prosser trap collections in Table I to demonstrate intermediacy. The counts followed the methods outlined by Hubbs and Lagler (*Bull. of Cranbrook Institute of Science, 26:8–13*, 1949). Fin ray and vertebrae counts were made from X-ray photographs.

Examination of principal characteristics usually revealed intermediacy. The angle of the maxillary of the squawfish is straight (180°), the chiselmouth's is decurved (130–140°); in the hybrid, the maxillary is decurved (150°). The jaw of the chiselmouth is a rectangular, hard, cartilaginous plate. The jaw of the hybrid and squawfish is rounded without hardened cartilaginous parts. The peritoneum of the chiselmouth is jet black. In the squawfish the peritoneum has little pigmentation. Peritoneum pigmentation in the hybrid is variable between that of the parents. The alimentary canal of the hybrid is "S" shaped, as in the squawfish. This differs from the convoluted chiselmouth intestine. Parasitism of the buccal cavity by hirudineans, which is prevalent in the chiselmouth and reduced in the squawfish of the Yakima River, occurs in the hybrid.

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The Yakima River chiselmouth × squawfish is apparently identical with *Leuciscus caurinus*, described by Snyder (*op. cit.*) and correctly identified as a hybrid by Hubbs and Schultz (*op. cit.*). Also, it is the same as the hybrid collected near King Hill by the latter authors.

The abundance of Yakima River examples imply that the chiselmouth × squawfish hybrid is not as rare as past records indicate. They can easily be misidentified as chiselmouth by persons inexperienced in squawfish and chiselmouth characteristics. Investigators working in the lower Columbia River have reported a fish that appeared to be a chiselmouth × squawfish hybrid, but unfortunately none could be obtained to verify this identification.—BENJAMIN G. PATTEN, *U. S. Bureau of Commercial Fisheries, Biological Laboratory, 2725 Montlake Blvd., Seattle 2, Washington.*

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SALINITY RELATIONS OF SOME FISHES IN THE ARANSAS RIVER, TEXAS

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SALINITY RELATIONS OF SOME FISHES IN THE ARANSAS RIVER, TEXAS[1]

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INTRODUCTION

Fishes inhabiting bays and estuaries along the lower Gulf coast of Texas are at times subject to extremes in temperature and salinity. During droughts evaporation is high and salinity tends to increase during most months of the year. A question often discussed is: What part does salinity play in affecting distribution and abundance of fishes inhabiting this area?

Several workers have studied salinity relations of fishes in the inshore waters along the eastern and southern coasts of the United States. Hildebrand and Schroeder (1928) studied the fishes of Chesapeake Bay and included salinity records in many of their observations. Gunter (1945) published an extensive account of the distribution of the marine fishes of Texas as related to salinity. Gunter (1950) studied distribution and abundance of fishes in marginal ponds and salt flats in the Aransas National Wildlife Refuge with emphasis on changes due to temperature and salinity. The latter two studies were made during periods of normal or above normal rainfall. Simpson and Gunter (1956) described the effects of salinity on Gulf coast cyprinodonts during an extremely dry period. Simmons (1957) studied the problem in the usually hypersaline Laguna Madre of Texas.

Reid (1954) surveyed ecological relations of the fishes near Cedar Key, Florida. Reid (1955, 1956, 1957) published accounts of the changes in abundance and distribution of fishes in East Bay, Texas, before and after construction of an artificial pass connecting the blind end of that bay with the Gulf of Mexico. Kilby (1955) studied the fishes of Cedar Key and Bayport, Florida, and the extent to which salinity affected their distribution. Bailey, Winn, and Smith (1954), in their accounts of the fishes of the Escambia River, Alabama and Florida, recorded salinity relations of many marine and freshwater fishes. Because abrupt salinity stratification occurred in the Escambia River at times, Bailey *et al.* (1954) were not always able to determine the exact salinity in which some of their specimens were living. Springer and Woodburn (1960) discussed the effects of salinity, temperature, and vegetation on the distribution of fishes in the Tampa Bay area.

The objective of this study was to note the occurrence of fishes found at three stations on the Aransas River under conditions of varying salinities. The study began during September 1956 at the height of one of the worst droughts ever recorded for this section of the United States. Field work was concluded in November 1957, six months after the drought was broken by heavy rains which fell during the summer of 1957. Two aspects which previous authors have not had an opportunity to study extensively are emphasized in this paper. First, the populations sampled came from habitats in which salinity was an important variable. Secondly, variation in salinity occurring in the river provided opportunities for study of the interaction of freshwater and marine fishes.

DESCRIPTION OF THE AREA

The Aransas River has its source at approximately latitude 28°17′N. and longitude 97° 40′ W. It terminates at Copano Bay, which is connected to the Gulf of Mexico through Aransas Bay and Aransas Pass (fig. 1). Except for drainage of water after rains there is no net seaward flow. Water stands only in the lower 28 miles of the river bed as the result of ground water addition and backup of water from the secondary bays. The river averages 100 feet in width and about 3 feet in depth although occasional deep holes may range to a depth of 15 feet.

Vegetation in the river was scanty, probably as a result of extremes in salinity. Along certain stretches of the banks were found emergent plants such as sedges, water hyssops, willows, rushes, grasses, and pondweeds. Dominant algae were a blue-green alga, *Phormidium* sp., and a green alga, *Cladophora* sp. The amount of this algal vegetation increased during the latter half of 1957 with the advent of increased precipitation and lowered salinities.

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[1] Part of a thesis presented to the Faculty of the Graduate School of the University of Texas in partial fulfillment of the requirements for the degree of Master of Arts.

Salinity of the river appeared to be controlled by: (1) precipitation, (2) evaporation, (3) intrusion of salt water from Copano Bay, (4) invasion of highly saline water from Chiltipin Creek which was polluted with brine wastes from oil fields. Salinities found at each station during the study are shown in Figure 2. Precipitation was recorded at Beeville, Texas, which lies in the middle of the watershed. Figure 2 shows that small amounts of rainfall merely dilute the saline water in the river while periods of heavy rainfall cause floods which flush it into the bays.

METHODS

Stations were sampled every 4 to 6 weeks at which time air temperature, water temperature, weather conditions, and vegetation were observed. Samples of water to be measured for salinity were taken at the surface and at a depth of 2 feet. Salinity was determined by titration with silver nitrate. Table 2 summarizes temperature - salinity conditions observed at the three stations.

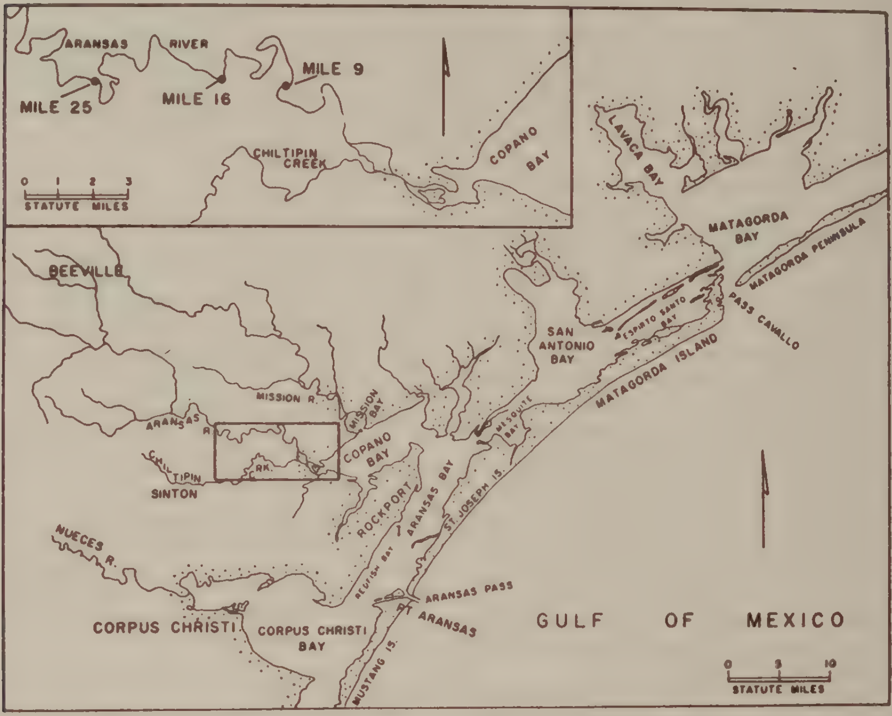
ARANSAS RIVER
MILE 9
MILE 25
MILE 16
CHILTIPIN CREEK
COPANO BAY
0 1 2 3
STATUTE MILES
LAVACA BAY
MATAGORDA BAY
MATAGORDA PENINSULA
BEEVILLE
SAN ANTONIO BAY
ESPIRITO SANTO BAY
PASS CAVALLO
MATAGORDA ISLAND
MISSION R.
MISSION BAY
ARANSAS R.
MESQUITE BAY
COPANO BAY
CHILTIPIN CK.
SINTON
ROCKPORT
ARANSAS BAY
ST. JOSEPH IS.
NUECES R.
REDFISH BAY
ARANSAS PASS
PT. ARANSAS
CORPUS CHRISTI
CORPUS CHRISTI BAY
MUSTANG IS.
GULF OF MEXICO
0 5 10
STATUTE MILES

Figure 1. Central Texas coast showing location of study area.

During April, May, and June 1957 the two lower stations were not sampled due to impassable roads.

No attempt was made to sample all fish species present in the river. The data presented concern only those fishes which could be sampled within a limited area and depth along the shore. The same 30-foot bag seine was used for all collections. It was 4 feet high with wings of ⅓-inch bar mesh and bag of ¼-inch bar mesh. At each station the seine was hauled either once or twice parallel to the shore over fixed paths and distances. All fish taken at a station were immediately preserved in 10 percent formalin for subsequent examination. All measurements are standard lengths to the nearest millimeter. Table 1 summarizes the distribution by salinity of the fishes collected.

Stations at 9, 16, and 25 miles from the mouth of the river being most accessible were selected as collection sites (fig. 1). Mile 9 and Mile 25 had gently sloping bottoms. At Mile 16 the bottom sloped gently for about 8 feet, then more abruptly so that at a distance of 12 feet offshore the depth had increased to 6 feet. The bottom at all three stations consisted of silt and mud.

Salinities Recorded for Species Observed

Lepisosteus spatula Lacépède, Alligator gar—Only three alligator gars were taken with the type of gear used although the

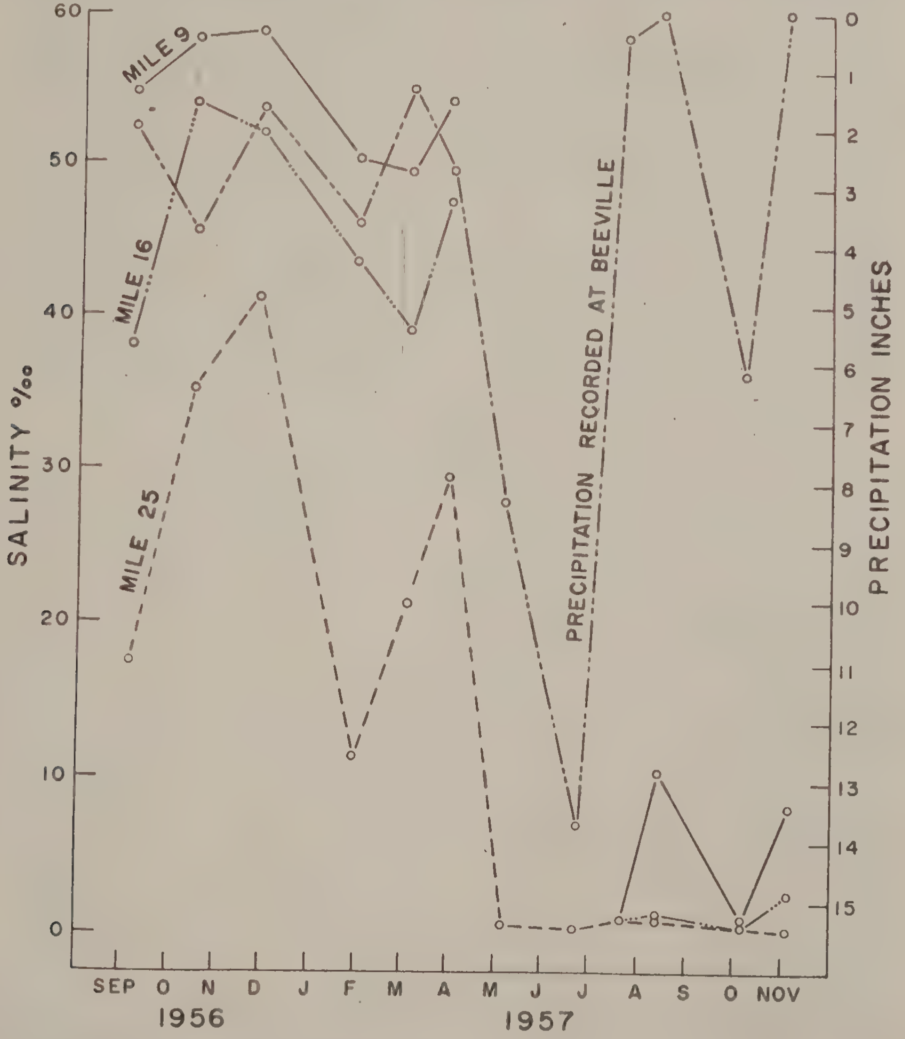

Figure 2. Salinity regimes—Aransas River. Precipitation at Beeville, Texas is the cumulative total recorded between collections.

species was abundant in the river at all times. One specimen approximately 1 meter long was captured at Mile 25 in October 1956 in a salinity of $35.2^0/_{00}$. Another was taken in October 1957 at Mile 25 in a salinity of $0.05^0/_{00}$. It measured 425 mm in length. The third was a small specimen 70 mm long collected in November 1957 in a salinity of $8.3^0/_{00}$ at Mile 9. Gars were observed in the river during every month of the year and in every salinity (0.05 to $58.6^0/_{00}$).

Brevoortia patronus Goode, Largescale menhaden.—One specimen 120 mm long was collected at Mile 9 in March 1957 in a salinity of $54.3^0/_{00}$. At the same time at Mile 16 another specimen measuring 32 mm was taken in $47.6^0/_{00}$. In July 1957 three individuals, 52, 61, and 64 mm long were found at Mile 16 in $0.5^0/_{00}$.

Dorosoma cepedianum (LeSueur), Gizzard shad.—Sixty specimens were collected in salinities ranging from $0.05^0/_{00}$ to $41.3^0/_{00}$. No juvenile fish were taken in the first half of the study when the river was highly saline. Forty specimens less than 40 mm long were caught in July 1957 in salinities of $1.1^0/_{00}$ or less. No small individuals were taken in salinities above $1.1^0/_{00}$. This supports the conclusions of Gunter (1945) that the gizzard shad inhabiting coastal waters must return to fresh water to spawn. Only two adult gizzard shad were taken in highly saline water; one measuring 114 mm was caught in $35.2^0/_{00}$ and the other, 104 mm in length, was taken in $41.3^0/_{00}$.

Dorosoma petenense (Günther), Threadfin shad.—Thirty-three juveniles were collected. One specimen 35 mm in length was caught in a salinity of $10.4^0/_{00}$ at Mile 9 during August 1957. All others measured less than 60 mm in length and were taken in salinities of $1.0^0/_{00}$ or lower, indicating that this species also might require fresh water to spawn.

Anchoa mitchilli (Valenciennes), Bay anchovy.—A total of 228 individuals of this species was taken. They ranged from 23 to 57 mm in length although most were between 40 and 50 mm. Bay anchovies were found in salinities from $0.05^0/_{00}$ to $8.3^0/_{00}$ and none were taken during 1956 when the river was hypersaline.

Notropis lutrensis (Baird and Girard), Red shiner.—Three juveniles were collected in August 1957 in a salinity of $1.0^0/_{00}$.

TABLE 1.
Occurrence by salinity of fishes collected.

Salinity $^0/_{00}$	from:	.05	1.1	5.1	15.1	25.1	35.1	45.1	55.1
	to :	1.0	5.0	15.0	25.0	35.0	45.0	55.0	58.6
Collections in this salinity range		10	2	3	2	1	5	7	2
Lepisosteus spatula		1	—	1	—	—	1	—	—
Brevoortia patronus		3	—	—	—	—	—	2	—
Dorosoma cepedianum		47	5	6	—	—	2	—	—
Dorosoma petenense		32	—	1	—	—	—	—	—
Anchoa mitchilli		114	79	35	—	—	—	—	—
Notropis lutrensis		3	—	—	—	—	—	—	—
Ictalurus furcatus		1	—	1	—	—	—	—	—
Syngnathus scovelli		1	—	—	143	—	21	—	—
Fundulus grandis		8	—	11	2	—	4	17	2
Lucania parva		45	—	—	3	6	19	1	—
Cyprinodon variegatus		144	12	46	28	11	173	161	13
Gambusia affinis		22	6	1	4	—	—	—	—
Mollienisia latipinna		13	—	2	61	1	129	1	—
Menidia beryllina		285	124	75	302	484	137	77	7
Mugil cephalus		10	1	18	57	9	30	31	4
Mugil curema		1	—	—	—	—	—	—	—
Micropterus salmoides		—	—	—	1	—	—	—	—
Chaenobryttus gulosus		—	—	—	2	—	—	—	—
Lepomis macrochirus		41	8	—	6	—	—	—	—
Lepomis megalotis		4	—	—	—	—	—	—	—
Bairdiella chrysura		—	2	—	—	—	—	—	—
Eucinostomus argenteus		—	—	3	—	—	—	—	—
Cichlasoma cyanoguttatum		7	1	—	4	—	—	—	—
Dormitator maculatus		—	—	—	—	—	—	1	—
Gobiosoma bosci		1	—	—	4	—	—	—	—
Trinectes maculatus		1	1	1	—	—	—	—	—

Ictalurus furcatus (LeSueur), Blue catfish.—Two specimens of this fresh-water catfish were taken. One measured 104 mm and was found at Mile 16 in a salinity of $1.0^{0}/_{00}$. The second, measuring 85 mm in length, was caught in a salinity of $10.4^{0}/_{00}$ at Mile 9. Gunter (1945) found a few blue catfish in salinities up to $6.9^{0}/_{00}$ in Copano Bay.

Syngnathus scovelli (Evermann and Kendall), Gulf pipefish.—In September 1956, 164 specimens were collected from two stations. Twenty-one came from a salinity of $38.1^{0}/_{00}$ at Mile 16 and 143 were found in a salinity of $17.4^{0}/_{00}$ at Mile 25. Nearly all the males were either carrying developing eggs and embryos or had recently delivered broods (as indicated by their enlarged, flaccid pouches). One other pipefish, a ripe female measuring 89 mm, was taken in a salinity of $0.06^{0}/_{00}$ during June 1957.

Pipefish are usually found in or near submerged vegetation, and salinity might well affect their distribution and abundance by altering the amount of vegetation available to them. Simmons (1957) found this species abundant in vegetation in salinities to $45^{0}/_{00}$.

Fundulus grandis Baird and Girard, Gulf killifish.—Forty-four Gulf killifish ranging in length from 21 to 90 mm were taken in salinities of 0.05 to $58.6^{0}/_{00}$. Table 2 shows that this species occurred throughout a wide range of salinity-temperature combinations. Small and large killifish were found together in both fresh and hypersaline water. Simpson and Gunter (1956) took *F. grandis* in salinities varying between $1.8^{0}/_{00}$ and $76.1^{0}/_{00}$.

Lucania parva (Baird and Girard), Rainwater killifish. — Seventy-four specimens ranging in length from 9 to 32 mm were collected in salinities from $0.05^{0}/_{00}$ to $47.6^{0}/_{00}$. Sixteen were taken at one station in a salinity of $38.1^{0}/_{00}$, and only four were caught in salinities above this. Over 60 percent were found in salinities less than $10.0^{0}/_{00}$.

Gunter (1945) found this species most abundant in salinities between $10.0^{0}/_{00}$ and $15.0^{0}/_{00}$. Kilby (1955) took 81 percent of his specimens from waters of $10^{0}/_{00}$ or less. Simpson and Gunter (1956) found 39.4 percent of the rainwater fish they collected in salinities below $10.0^{0}/_{00}$, the greater proportion having been taken at salinities between $18.4^{0}/_{00}$ and $48.2^{0}/_{00}$. In Florida, Springer and Woodburn (1960) found this species to be most common in salinities greater than $25^{0}/_{00}$. They stated that vegetation rather than salinity is probably the most important factor affecting its distribution.

Cyprinodon variegatus Lacépède, Sheepshead minnow.—A total of 588 sheepshead minnows was collected, accounting for 18.5 percent of all fishes taken. They were found in salinities ranging from $0.05^{0}/_{00}$ to $58.6^{0}/_{00}$.

Simpson and Gunter (1956) caught 2,009 *C. variegatus* in a salinity of $142.4^{0}/_{00}$ and stated that, so far as they knew, "this was the highest salinity at which living fishes have been reported." During August 1957 the writer kept one specimen in a small aquarium for 7 days in a salinity of $125.2^{0}/_{00}$ and when the salinity was raised to $145.6^{0}/_{00}$ by the addition of sea-salt crystals, it lived an additional 37 hours. However, as Simpson and Gunter *(op cit)* emphasize, "water at such salinity is not sea water for some salts are precipitated before sea water attains such concentration and the salt complex is changed."

In December 1957 a pair of *C. variegatus* kept in an aquarium in the laboratory spawned four eggs. These eggs were transferred to a shallow glass dish 100 mm in diameter and filled with sea water to a depth of 25 mm. The dish was placed in a water-filled pan to avoid rapid changes in temperature and the eggs were observed daily. On the afternoon of the 12th day the eggs had not hatched, but on the morning of the 14th day three larval fishes were found darting rapidly around the dish. They measured 4 mm in standard length and had absorbed their yolk sacs. Evaporation had decreased the depth of the water in the dish to 8 mm and salinity was in excess of $110^{0}/_{00}$. Temperature during incubation ranged from 17.4° C to 27.5°C. Within the ranges recorded, increasing salinity and changes in temperature did not inhibit incubation of the eggs and young were able to survive in hypersaline water.

There appears to be no correlation between size and salinity as small and large specimens were found in all salinities encountered. Radical changes in abundance were not noted even during periods of extremes in salinity and temperature (Table 2).

TABLE 2.

Salinity-temperature conditions at three stations on the Aransas River and the number of individuals of several species taken therein.

Date	Station	Salinity $^0/_{00}$	Water temperature °C	*Fundulus grandis*	*Lucania parva*	*Cyprinodon variegatus*	*Molliensia latipinna*	*Menidia beryllina*	*Mugil cephalus*
9/ 4/56	9	54.9	29.3	1	—	6	—	—	2
	16	38.1	27.9	3	16	90	95	76	8
	25	17.4	29.8	—	2	7	59	148	2
10/14/56	9	58.2	29.5	—	—	—	—	1	4
	16	54.0	28.0	—	—	3	—	2	—
	25	35.2	29.6	—	—	—	—	—	4
11/25/56	9	58.6	16.0	2	—	13	—	6	—
	16	52.2	16.0	—	—	8	1	31	—
	25	41.3	18.6	—	3	4	34	51	—
1/30/57	9	50.3	16.0	3	—	52	—	6	1
	16	43.9	20.5	—	—	62	—	1	2
	25	11.4	18.9	1	—	3	—	58	17
3/ 2/57	9	49.5	21.0	3	—	15	—	7	8
	16	39.0	21.2	1	—	17	—	9	16
	25	21.0	21.0	2	1	21	2	157	55
3/30/57	9	54.3	21.2	10	—	30	—	20	9
	16	47.6	21.2	—	2	47	—	11	11
	25	29.5	21.2	—	6	11	1	481	9
5/ 5/57	25	0.08	24.2	—	—	7	11	2	10
6/22/57	25	0.06	26.2	—	4	—	—	1	—
7/20/57	9	0.7	—	5	—	90	—	—	—
	16	0.5	—	—	—	4	—	—	—
	25	1.1	34.5	—	—	—	—	101	1
8/14/57	9	10.4	32.9	6	—	21	—	—	1
	16	1.0	31.2	—	—	7	—	5	—
	25	1.0	31.2	—	2	2	2	98	—
10/ 5/57	9	0.8	27.2	1	—	12	—	13	—
	16	0.06	27.0	—	—	5	—	6	—
	25	0.05	29.0	2	1	—	—	2	—
11/ 2/57	9	8.3	24.6	4	—	22	2	17	—
	16	2.7	24.5	—	—	12	—	23	—
	25	0.2	24.2	—	38	17	—	158	—

Gambusia affinis (Baird and Girard), Mosquitofish.—Thirty-three specimens from 9 to 36 mm long were collected. All but five were taken in salinities of 1.1$^0/_{00}$ or less. In September 1946 four specimens were found in a salinity of 17.4$^0/_{00}$. During November 1957 one mosquitofish measuring 19 mm was found in a salinity of 8.3$^0/_{00}$ at Mile 9.

Simpson and Gunter (1956) caught one *G. affinis* in a salinity of 20.6$^0/_{00}$. Kilby (1955) stated: ". . . it thus appears that the fish is most numerous in protected waters such as shallow pools and vegetated areas where the salinities are lowest, at least periodically, but it can tolerate salinities up to at least 26$^0/_{00}$."

Mollienisia latipinna LeSueur, Sailfin molly.—Two hundred and seven individuals ranging between 12 and 44 mm in length were caught in salinities of 0.08$^0/_{00}$ to 52.2$^0/_{00}$. This species is ordinarily found in schools and thus capture is, for the most part, fortuitous. In fact, three seine hauls accounted for more than 90 percent of the specimens collected.

Herre (1929) noted the remarkable salinity tolerance of *M. latipinna* in populations which had been transported from the United States via the Hawaiian Islands and accidentally naturalized in the Philippine Islands. He found the species to be abundant in salinities from 32$^0/_{00}$ to 87$^0/_{00}$, and that the latter salinity appeared to be near its limit of toleration, for in ponds with a salinity of $94^{0}/_{00}$, it had entirely disappeared.

Menidia beryllina (Cope), Tidewater silverside.—A total of 1,491 individuals was collected. The tidewater silverside is probably the most abundant species in the area sampled. They were found in salinities from $0.05^{0}/_{00}$ to $58.6^{0}/_{00}$ and in widely differing combinations of salinity and temperature. Collections taken over a wide range of salinities had both small and large specimens in fairly constant ratios. Gunter (1945) found specimens of *M. beryllina* to be slightly larger in waters above $25^{0}/_{00}$ than in those below that salinity.

Mugil cephalus Linnaeus, Striped mullet. —One hundred and sixty striped mullets were collected during this study. Adult mullets easily escaped the collecting gear used, and only six specimens captured were more than 100 mm long. The great majority were juveniles measuring 22 to 42 mm taken from March to May 1957. Juveniles were found in salinities ranging from $0.08^{0}/_{00}$ to $54.3^{0}/_{00}$. Larger mullets were observed jumping in the river during every month and in every salinity encountered. Mullets at all ages are euryhaline.

Since it is difficult to separate immature *M. cephalus* and *M. curema,* it is possible that some of the smaller specimens were *M. curema.*

Mugil curema Valenciennes, White mullet.—One white mullet measuring 79 mm was taken at Mile 25 in a salinity of $0.2^{0}/_{00}$. Its fins were heavily infested with leeches.

Micropterus salmoides (Lacépède), Largemouth bass.—At Mile 25 on September 4, 1956 a largemouth bass 151 mm long was caught in a salinity of $17.4^{0}/_{00}$. Two other species of the family Centrarchidae and one cichlid species were included in this unusual collection. It is unfortunate that further salinity determinations for the upper reaches of the river were not made on this date to determine the salinities these typically fresh-water species passed through to reach this station. Hildebrand and Schroeder (1928) reported *M. salmoides* from a salinity of $12.87^{0}/_{00}$ taken at Lewisetta, Virginia, in August 1921. Of the 18 specimens reported in Kilby's (1955) collections, only 1 was taken where the salinity reached $11.8^{0}/_{00}$. Renfro (1959) concluded that salinities above $9^{0}/_{00}$ were progressively more critical, but that this species might be expected to survive several weeks in lower salinities.

Chipman (1959) studied fishes in a Louisiana pond which was polluted with oil well brine wastes. He noted mortalities of fresh-water species which died during a 7-day period in which salinity was first recorded at $16.5^{0}/_{00}$, rose to $20.9^{0}/_{00}$ on the 5th day, declined to $5.8^{0}/_{00}$ and $6.6^{0}/_{00}$ respectively on the 6th and 7th days. He found one largemouth bass dead in a salinity of $20.6^{0}/_{00}$.

Chaenobryttus gulosus (Cuvier), Warmouth.—Two specimens measuring 68 and 72 mm taken in the collection mentioned above (salinity $17.4^{0}/_{00}$) were the only two warmouths observed.

During his 7-day study Chipman (1959) found 748 warmouths dead. He found in laboratory toxicity experiments that 12 specimens tested died in salinities between $10.7^{0}/_{00}$ and $16.9^{0}/_{00}$.

Lepomis macrochirus Rafinesque, Bluegill. —Six subadults were taken at Mile 25 September 4, 1956 in $17.4^{0}/_{00}$. On November 2, 1957 six young specimens 28 to 35 mm in length were collected at Mile 16 in $2.7^{0}/_{00}$. The remaining 43 bluegills taken were found in salinities of $1.1^{0}/_{00}$ or less and ranged in length from 16 to 83 mm. Chipman (1959) noted 523 dead bluegills during his 7-day study.

Lepomis megalotis (Rafinesque), Longear sunfish.—Four subadults were taken in collections during the latter half of 1957. All were caught in salinities of $0.2^{0}/_{00}$ or less.

Bairdiella chrysura (Lacépède), Silver perch.—Two specimens measuring 86 and 93 mm were taken on November 2, 1957 in a salinity of $2.7^{0}/_{00}$. Gunter (1945) found this species to be more or less indifferent to salinity. Kilby (1955) caught silver perch in salinities from $5.6^{0}/_{00}$ to $27.3^{0}/_{00}$. Springer and Woodburn (1960) took this species in salinities from $3.7^{0}/_{00}$ to $35.0^{0}/_{00}$ with most being captured in salinities above $20.0^{0}/_{00}$.

Eucinostomus argenteus Baird and Girard, Spotfin mojarra.—Three young individuals 40, 41, and 43 mm long were caught at Mile 9 in a salinity of $8.3^{0}/_{00}$. Species identification of this difficult genus is provisional.

Cichlasoma cyanoguttatum (Baird and Girard), Rio Grande perch.—Twelve Rio Grande perch were taken during the study, four being found in the collection of September 4, 1956 at Mile 25 in $17.4^0/_{00}$. The remaining specimens were taken at various times in salinities of $1.1^0/_{00}$ or less.

Dormitator maculatus (Bloch), Fat sleeper.—One specimen 38 mm long was caught on September 5, 1956 at Mile 9 in a salinity of $54.9^0/_{00}$. As this species is known to penetrate far inland (Moore 1957) it appears to be tolerant to a wide range of salinities.

Gobiosoma bosci (Lacépède), Naked goby.—Five specimens were collected, three being taken in $21.1^0/_{00}$, one in $17.4^0/_{00}$, and one in a salinity of $0.2^0/_{00}$.

Trinectes maculatus (Bloch and Schneider), Hogchoker. — Three hogchokers were taken in salinities of $0.8^0/_{00}$, $2.7^0/_{00}$, and $8.3^0/_{00}$. Simmons (1957) stated that the hogchoker was common in salinities of $50^0/_{00}$ or less during the fall months in the Laguna Madre.

DISCUSSION AND SUMMARY

During this study salinity in the river varied over a broad range and fluctuations were sometimes rapid. Water levels were constant except during floods; water temperatures observed varied from 16.0° C to 34.5° C, and the shore and bottom configuration was stable. Most of the species taken were those which are characteristically found along the shoreline, and it must be emphasized that the conclusions reached do not extend to the fishes which were undoubtedly present in the river but which were not taken with the gear used.

As previously stated, the objective of the study was to note the occurrence of fishes in varying salinities. It is felt that the data obtained allow inferences concerning salinity tolerances. Salinity tolerance as here used is construed to be the capacity of a fish to endure specific levels of dissolved salts. The writer is aware that the relationship of a fish to its environment is a complex phenomenon. A fish is obliged to adjust not only to changing salinity, but to changes in temperature, dissolved oxygen concentration, food supply, and numerous other interrelated parameters of its environment. In the case of critical salinities (those concentrations of dissolved salts too low or high for the fish to withstand indefinitely) we might expect exposure time to become a factor. That is, in increasingly more critical salinities, the fish's survival time must decrease. For this reason, it is possible that some of the fishes taken were transients, being found in salinities higher or lower than they could withstand for more than limited intervals.

Twenty-six species belonging to 8 orders and 16 families were collected. Nine species (*Dorosoma petenense, Notropis lutrensis, Ictalurus furcatus, Gambusia affinis, Micropterus salmoides, Chaenobryttus gulosus, Lepomis megalotis, Lepomis macrochirus*, and *Cichlasoma cyanoguttatum*) are fresh-water fishes, i.e., they are found in fresh water and occur in salt waters only occasionally or in reduced numbers. Five of these species were found in a salinity of $17.4^0/_{00}$, which indicates that they have at least temporary tolerance to this salinity.

Why then do not these fresh-water fishes occur in greater numbers when the salinity in the river has been decreased to a level which they are known to tolerate? Probably they do not because of the innate characteristics of this particular hydrographic system. When salinity is lowered these fishes venture into the lower reaches of the river. Before their numbers can reach significant proportions, however, the salinity begins to increase and they are either forced back upstream or perish. Population densities of these "fresh-water" species appear to vary inversely with salinity.

The gar, *Lepisosteus spatula*, and the clupeid, *Dorosoma cepedianum*, were tolerant of all salinities observed and might well be considered euryhaline. Presumably spawning must take place in fresh water.

Eight species (*Brevoortia patronus, Anchoa mitchilli, Syngnathus scovelli, Bairdiella chrysura, Eucinostomus argenteus, Gobiosoma bosci, Trinectes maculatus*, and *Mugil curema*) are commonly found during part or all of their lives in salinities between fresh water and sea water. With the exception of the goby, all enter the Gulf at times. However, these species are probably not well adapted for life in salinities above $35^0/_{00}$.

The remaining seven species (*Fundulus grandis, Lucania parva, Cyprinodon variegatus, Mollienisia latipinna, Menidia beryllina, Mugil cephalus*, and *Dormitator maculatus*) are particularly fitted for life in a wide range of salinities. They are able to maintain their populations in the river regardless of changes in salinity. Most of these species were represented in collections in which salinity and temperature were at extreme levels. They are among the hardiest of the smaller fishes found along the coast of the Gulf of Mexico. These are the fishes found most often and in greatest aboundance along the shorelines of inside waters of the northwestern Gulf of Mexico.

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ABSTRACT

Fishes were collected at three stations on the Aransas River, a non-flowing, normally brackish body of water on the Central Texas Gulf Coast. A drought prevailing during the first half of the study produced a highly saline environment. Subsequent rainfall and lowered salinities provided an opportunity to note the occurrence of fishes taken at three stations over a wide range of salinities. Twenty-six species are categorized as to their salinity tolerance. Five species of freshwater fishes were found in a salinity of $17^0/_{00}$. Seven species were found to tolerate salinities ranging from nearly fresh to well above $45^0/_{00}$.

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DISTRIBUTION OF THE BOTTLE-NOSED DOLPHIN IN THE LEEWARD HAWAIIAN ISLANDS

Data on the geographical distribution of most of the smaller species of cetaceans are inadequate. The following observations of bottle-nosed dolphins, *Tursiops truncatus*, are therefore recorded. Observations were made incidental to other studies in the Leeward Chain of the Hawaiian Archipelago, an area seldom visited by zoologists. During my residence at Midway Atoll from November 1956 until July 1958, I made frequent low-altitude reconnaissance flights over all the islands and atolls in the Leward Chain, and traversed by ship at least twice the entire length of the Leeward Chain, except for that portion between Midway Atoll and Laysan Island. As far as I can determine, the literature records the occurrence of no species of dolphins in the Leeward Islands. The only other species of cetacean I observed in the area was the sperm whale, *Physeter catodon*, which was not uncommon on the open ocean.

Kure Atoll.—I made two cruises to Kure Atoll, on 5 June 1957 and 9 May 1958. On both occasions, when the vessel was within 2 km. of the reef, schools of bottle-nosed dolphins, numbering about a dozen individuals, approached and played ahead of our bow.

Midway Atoll.—Bottle-nosed dolphins were frequently observed in the waters outside, and within 1 km. of, the reef. The largest school, containing at least 50 individuals, was seen on 24 January 1957. Through a natural break on the west side of the reef, they sometimes enter the lagoon, where they remain in the deeper portion known as Welles Harbor. They were occasionally reported from the ship channel between Sand and Eastern Islands.

Pearl and Hermes Reef.—On 14 March 1958, I observed from the air a school of about 30 dolphins in the shallow water just outside the southwest portion of the reef.

Laysan Island.—On 27 May 1958, a half dozen bottle-nosed dolphins played alongside the ship for a few minutes in shoal water about 3 km. southeast of Laysan Island.

French Frigate Shoals.—On 26 May 1958, a single bottle-nosed dolphin ran ahead of our bow about 10 km. south of La Perouse Pinnacle at French Frigate Shoals.

My failure to find dolphins at Lisianski Island, Maro Reef, Necker Island, and Nihoa does not preclude the possibility of their occurrence there.

It is of interest to note that all of the above sightings were made over relatively shallow water inside, or within a kilometer of, the 18-meter (10-fathom) depth contour. However, on 5 June 1958, I saw a small school of three gray dolphins with long snouts on the open ocean about 100 km. (55 nautical miles) southeast of French Frigate Shoals. They could have been bottle-nosed dolphins, but they swerved away from the ship, leaping high, and did not come close enough for positive identification. Elsewhere in its range, the bottle-nosed dolphin is predominantly an inshore species, its seaward distribution roughly delimited by the same contour (cf. Gunter, Fishery Bull., U. S. Fish and Wildlife Serv., 55: 548, 1954; Moore, Amer. Midland Nat., 49: 134, 1953). Its distribution is nearly world-wide, though apparently discontinuous. Are the populations local and isolated, or migratory and intermingling? The infrequency of observations far at sea would favor the former hypothesis.

No specimens have been collected in the Hawaiian Islands. All Pacific populations of *Tursiops truncatus* were referred to the race *gilli* by Tomilin (Zveri SSSR Prilezhashchikh Stran. Vol. IX Kitoobraznye. Publ. Akad. Nauk. SSSR, Moscow, 1957). However, in view of the probable isolation of the various populations, a reassessment of geographical variation in the entire species is needed. *Tursiops truncatus* is easily distinguished from *Tursiops aduncus* by the uniform coloration of its underparts, a characteristic readily observed as the animals corkscrewed under the bow.

I wish to thank the men of the U. S. Naval Station, Midway Islands, and of the U. S. Coast Guard cutters *Matagorda* and *Chautauqua*, for making these observations possible. Karl W. Kenyon, Victor B. Scheffer, and Ford Wilke offered helpful suggestions during the preparation of this note.—DALE W. RICE, *U. S. Fish and Wildlife Service, Sand Point Naval Air Station, Seattle 15, Washington.* *Received 29 May 1959.*

POPULATION DYNAMICS OF THE HAWAIIAN MONK SEAL

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POPULATION DYNAMICS OF THE HAWAIIAN MONK SEAL

DALE W. RICE

POPULATION DYNAMICS OF THE HAWAIIAN MONK SEAL

By Dale W. Rice

From October 1957 through July 1958, I was able to make intensive observations on Hawaiian monk seals, *Monachus schauinslandi*, throughout their entire range. More data on population dynamics are now available than when an earlier paper (Kenyon and Rice, 1959) was completed.

FIELD WORK

During the course of the present study, aerial surveys were made of all the islands in the Leeward Chain and landings were made on all but two of the six atolls where seals breed.

Both aerial counts and ground counts were made to determine the present size of the monk seal population. Aerial counts were made from Navy UF-1 Grumman Albatross amphibians flying at about 220 km. per hour at altitudes of 6 to 150 m. Ground counts were made by walking the beaches of the larger islands and by landing on, or closely approaching by small boat, the smaller sandspits.

The dates during which field work was conducted at each atoll are listed below:

Kure Atoll.—I landed on Green Island, Kure Atoll, on 9 May 1958, between 0845 and 1630, and closely observed all the sandspits west of Green Island from an outboard motorboat. Four aerial surveys were conducted at Kure, on 18 December 1957, and 14 April, 2 May, and 28 June 1958.

Midway Atoll.—The most intensive field work was conducted at Midway, where I was stationed from 17 November 1956 through 18 May 1958, and from 12 June 1958 through 21 July 1958, except for a few brief absences. Observations on seals were made several times weekly throughout this period. Since October 1957, eight aerial surveys were made at Midway, on 14 October, 18 and 28 December 1957, and 24 January, 14 April, 2 May, 16 and 28 June 1958.

Pearl and Hermes Reef.—I made six aerial surveys at Pearl and Hermes Reef during the course of this study. These were conducted on 14 October and 18 December 1957, and 24 January, 14 April, 2 May, and 16 June 1958. No landing was attempted.

Lisianski Island.—I made two aerial surveys of Lisianski Island, one on 28 December 1957, the second on 28 June 1958.

Laysan Island.—I spent the period 27 May to 4 June 1958 on Laysan Island. In addition, aerial surveys were conducted on 28 December 1957 and 28 June 1958.

French Frigate Shoals.—I made two aerial surveys of French Frigate Shoals on 28 and 30 December 1957, and went ashore on Tern Island on 26 May 1958; on several of the other islets in the atoll, a count of seals was made from a whaleboat or from the bridge of the cutter *Matagorda*. Additional data on seals at this atoll were supplied by the U. S. Coast Guard personnel stationed there.

Other areas.—Although monk seals straggle as far as the island of Hawaii, I never observed them either in the main islands or any of the other Leeward Islands. There is one record of two seals seen at Maro Reef (Bailey, 1952). None was seen during three low-altitude aerial surveys of this reef on 28 and 30 December 1957, and 28 June 1958. This extensive shallow reef appears to offer unsatisfactory hauling grounds; it is unlikely that it would be used as a pupping area because of the lack of sandy islets and spits, and the fact that even the highest rocks are awash only at low tide. At Nihoa Island, I saw no seals on 28 December 1957. Seals have not been reported here since 1857 and the exposed nature of the one tiny stretch of beach on this precipitous rocky island makes it improbable that seals ever bred here.

RESULTS

Population size.—The highest counts of adult and subadult seals made at each atoll during the study period are presented in Table 1. The total count for the species' entire range was 1,037. The relation of the count to the true population is difficult to estimate as the number of seals hauled out where they can be counted varies with season, time of day, and perhaps weather. The entire population at a given atoll is perhaps never ashore at one time. However, under favorable conditions, counts at each atoll approach a fairly consistent maximum, suggesting that most of the seals are hauled out. The counts, therefore, are not appreciably below the actual populations. However, a large proportion of the yearling class was doubtless missed (see *Age groups*). Including 169 pups born this season, the minimum number of Hawaiian monk seals alive in the spring and early summer of 1958 was 1,206 (Table 1). To estimate the total population, I have assumed that the entire yearling class was missed during the counts and have, therefore, added 150. Doubtless a few yearlings were seen, but the error introduced by their inclusion will tend to be counterbalanced by adults missed. On this basis, I estimate the present Hawaiian monk seal population at approximately 1,350.

All of the following calculations are based on actual counts of adult and subadult seals at each atoll and are thus subject to the same inaccuracies as these counts. However, the data are comparable *inter se*, so that the conclusions drawn from them remain valid.

Movements.—The accuracy of the census depends to a certain extent on the validity of the assumption that the seals are localized and that there is no appreciable movement between atolls. During 1957, 59 monk seals were tagged on three atolls as follows: Kure Atoll, 16; Midway Atoll, 18; Laysan Island, 25. Among 20 tagged seals examined at these atolls during the following year, I found none which had moved from one atoll to another.

TABLE 1.—*Counts of Hawaiian monk seals in the spring of 1958*

ATOLL	ADULTS AND SUBADULTS	PUPS	TOTAL
Kure Atoll	117	25	142
Midway Atoll	68	8	76
Pearl and Hermes Reef	286	52	338
Lisianski Island	247	34	281
Laysan Island	280	46	326
French Frigate Shoals	39	4	43
TOTALS	1,037	169	1,206

TABLE 2.—*Movements of tagged Hawaiian monk seals in Midway Atoll, 1958 (repeat observations of unweaned pups excluded)*

TAG NUMBER	AGE	SEX	TAGGED*		OBSERVED		DISTANCE FROM LAST PREVIOUS OBSERVATION, KM.
			Date	Locality	Date	Locality	
yrl.	MS- 3	♂	5 Mar. 57	Seal Island	22 Mar. 58	Seal Island	0.02
MS- 4	yrl.	♀	27 Mar. 57	Seal Island*	20 Apr. 58	Seal Island	0.03
MS- 9	pup	♂	11 Oct. 57	Dynamite Island*	22 Mar. 58	middle sandspit	0.20
MS-10	pup	♂	26 Aug. 57	Eastern Island*	22 Mar. 58	Seal Island	2.50
					27 Apr. 58	west sandspit	0.80
MS-34	ad.	♀	12 Nov. 57	Eastern Island	7 Jan. 58	Eastern Island	2.00
					20 Apr. 58	Seal Island	3.60
MS-38	pup	♂	3 Apr. 58	Eastern Island	11 Jul. 58	Eastern Island	0.50
MS-39	pup	♀	9 Apr. 58	Eastern Island	12 May 58	Eastern Island	0.10
MS-40	pup	♀	20 Apr. 58	Dynamite Island	1 Jul. 58	Eastern Island	1.10
					3 Jul. 58	Eastern Island	1.00
MS-41	pup	♀	26 Apr. 58	Dynamite Island	3 Jul. 58	Eastern Island	1.10
					18 Jul. 58	Eastern Island	0.50
MS-42	pup	♀	20 Apr. 58	middle sandspit	11 May 58	east sandspit	0.10
MS-43	pup	♂	20 Apr. 58	middle sandspit	1 Jul. 58	Eastern Island	1.30
					11 Jul. 58	Eastern Island	0.50
					18 Jul. 58†	Eastern Island	1.50
					18 Jul. 58‡	Eastern Island	2.00

* Or date and locality of last previous observation; see Kenyon and Rice (1959).
† 1,255 hours.
‡ 1,402 hours.

TABLE 3.—*Calculated population densities of the Hawaiian monk seal*

ATOLL	AREA OF SHOAL WATER (hectares)	SEAL POPULATION (winter 1957–58)	SEALS PER 100 HECTARES	HECTARES PER SEAL
Kure Atoll	6,200	117	1.89	53
Midway Atoll	8,800	68	0.77	130
Pearl and Hermes Reef	46,000	286	0.62	161
Lisianski Island (incl. Neva Shoal)	16,000	247	1.54	65
Laysan Island	2,600	280	10.77	9
French Frigate Shoals	50,000	39	0.08	1,282

Eighteen repeat observations of tagged seals at Midway Atoll, made since the previous report, confirm the fact that many of these animals may be found in the same general vicinity at intervals over considerable periods of time (Table 2).

Since the completion of the earlier paper, 70 additional seals have been tagged, including 58 at Laysan (No. MS-76 through MS-133) and 12 at Midway (MS-33 through MS-44).

Population density.—The concept of population density is difficult to apply to a littoral marine mammal whose wanderings at sea remain virtually unknown. Nevertheless, by applying available information, some tentative conclusions are indicated, which may throw light on the population dynamics of these animals.

Two observations suggest that monk seals do most of their feeding in the lagoons and on the shoals, rather than over the deep sea: (1) They are apparently quite sedentary and do not normally migrate. (2) From the few stomachs examined, they appear to be bottom-feeders which feed on coral-reef and shallow-water cephalopods and fish (Kenyon and Rice, 1959). The contents of a third seal stomach, found spewed on the beach of Seal Island, Midway Atoll, on 20 April, further confirmed these feedings predilections. It contained approximately 500 cc. of food items, identified as follows: 60 per cent (by volume), one goatfish, *Parupeneus* sp.; 40 per cent, one percomorph fish (Labridae or Sparidae).

The deepest water in which I observed monk seals was 29 m. (16 fathoms); this was one kilometer beyond the reef at French Frigate Shoals.

For calculating population densities, I have measured, on U. S. Coast and Geodetic Survey Hydrographic Charts, the water area within the 18.3 meter (10 fathom) contour at each atoll (Table 3). This represents the approximate limits of shoal water at each atoll. The reef platforms upon which the atolls are formed are quite flat-topped, and drop steeply to ocean depths of about 4,500 meters (2,500 fathoms). By using a deeper contour, the calculations of area would be only slightly larger.

On the above basis, calculated population densities varied from 0.08 to 10.77 seals per 100 ha., or 9 to 1,282 ha. per seal (Table 3).

Reproductive rate.—The total number of pups counted at each atoll in the spring of 1958 is presented in Table 1. Because of the extended pupping season, it is not possible to get

TABLE 4.—*Counts of Hawaiian monk seal pups, Spring 1958*

ATOLL	PUPS COUNTED, April	NEW PUPS COUNTED		TOTAL PUPS COUNTED, Spring 1958
		May	June	
Kure Atoll	10	12	3	25
Midway Atoll	8	0	0	8
Pearl and Hermes Reef	9	28	15	52
Lisianski Island	—	—	34	34
Laysan Island	—	46	0	46
French Frigate Shoals	—	4	—	4

TABLE 5.—*Summary of monk seal pups born at Midway Atoll, 1958*

BIRTH DATE	SEX	LOCALITY	REMARKS
1. 23 Oct. (est.)	♀	Eastern Island	Aborted fetus found 30 Oct.; length 54.5 cm., weight 3 kg.
2. early Feb.	?	Seal Island	Aborted fetus reported; length "ca. 18 in." Bones found 11 May.
3. early Feb.	?	Seal Island	Aborted fetus reported; length "ca. 18 in."
4. 14 Mar.	?	Seal Island	Stillborn, full term; collected 22 Mar.
5. 28 Mar.	♀	Eastern Island	Stillborn, full term; collected 29 Mar.
6. 31 Mar.	?	Rocky Island	Died ca. 11 Apr.; found dead 22 Apr.
7. 2 Apr.	♂	Eastern Island	Tagged MS-38; successfully weaned; last seen 11 July.
8. 8 Apr.	♀	Eastern Island	Tagged MS-39; successfully weaned; last seen 12 May.
9. 10 Apr.	♂	middle sandspit	Tagged MS-43; successfully weaned; last seen 18 July.
10. 15 Apr.	♀	Dynamite Island	Tagged MS-40; successfully weaned; last seen 3 July.
11. 16 Apr.	♀	middle sandspit	Tagged MS-42; successfully weaned; last seen 11 May.
12. 17 Apr.	♂	middle sandspit	Tagged MS-44; last seen 10 May with mother.
13. 24 Apr.	♀	Dynamite Island	Tagged MS-41; successfully weaned; last seen 18 July.

a complete count at one time; the earlier pups are weaned before the later pups are born. Although an occasional pup is born as early as December or as late as June, the majority are born between mid-March and mid-May. Three counts, made during the first half of April, May and June, should result in essentially complete counts. Since the nursing period in this species lasts about 35 days, I have assumed that any nursing pup, observed at least 35 days after the previous count, has been born since that count. Because nursing females and pups are quite stationary, I have also assumed that any nursing pup observed at a locality where none was seen on a previous count has been born since that count, regardless of the time interval. On the first count at each atoll, all pups, including weaned animals, were counted. On subsequent counts only nursing pups were counted, and they were included in the seasonal totals only when they were judged, on the basis of the above criteria, to have been born since the previous count. The results of individual counts at each atoll are presented in Table 4. These are in most cases a combination of both aerial and ground counts. They are believed to be nearly complete, except at Lisianski Island, where only one aerial survey could be made in late June, at which time most pups are weaned, with the resulting possibility of a number being missed. A total of 169 pups were counted throughout the range of the species this season.

The most complete data on the pupping season were obtained at Midway Atoll. There were 13 known pregnancies during the 1957–58 season (Table 5), resulting in three premature abortions, two full-term stillbirths, and eight successful live births. Of the eight live births, one pup died on or before the age of eleven days; its body, when found twelve days later, had a fractured skull which, however, might have been inflicted after death. Six of the remaining seven pups were successfully weaned, the other one probably so. The high rate of stillbirths at Midway may perhaps be attributed to the detonation of explosives during dredging operations in the ship channel, which passes close to the favorite hauling grounds of the seals. No dead pups were found at any of the other atolls, except at Laysan, where the mummified remains of one premature pup were found on the beach.

Reproductive rates, expressed as the number of live pups born per 100 adults and subadults, varied at each atoll from 10.3 to 21.4 per cent (Table 6). The birth rate for the population as a whole was 16.3 per cent, appreciably higher than that reported in 1957 on the basis of fewer data.

These reproductive rates do not help us to understand whether females breed annually or biennially. Even at atolls with high reproductive rates, the number of pups did not equal one-half the adult female population (see *Sex ratios* and *Age groups*). Female monk seals with pups invariably repulse adult males (in some seals, the females copulate while still nursing). These two facts might be interpreted as circumstantial evidence in favor of the theory of biennial breeding. However, there seem to be no biological reasons why a female monk seal should not breed in successive years. Female monk seals fast throughout the nursing period; it is possible that physiological exhaustion resulting from nursing a pup

TABLE 6.—*Calculated annual mortality, natality, and net increment of Hawaiian monk seal populations*

ATOLL	POPULATION		APPARENT MORTALITY		NATALITY SPRING 1958		APPARENT NET INCREMENT	
	spring 1957*	winter 1957–58	number	per cent	number	per cent	number	per cent
Kure Atoll	128	117	11	8.6	25	21.4	14	10.9
Midway Atoll	71	68	3	4.2	8	11.8	5	7.0
Pearl and Hermes Reef	290	286	4	1.4	52	18.2	48	16.6
Lisianski Island	256	247	9	3.5	34	13.7	25	9.8
Laysan Island	233	280	—	—	46	16.4	—	—
French Frigate Shoals	35	39	—	—	4	10.3	—	—

* Data from Kenyon and Rice (1959).

TABLE 7.—*Weights and measurements of newborn Hawaiian monk seals, Midway Atoll*

DATE 1958	SEX	AGE	WEIGHT, kg.	LENGTH, cm.	GIRTH, cm.	"DEGREE OF FATNESS" (girth/length)
28 Mar.	♀	Died at birth	15.2	97.9	45.5	46.5
2 Apr.	♂	4–19 hrs.	18.6	99.0	60.0	60.6
9 Apr.	♀	11.0–12.5 hrs.	19.3	106.0	63.0	59.4

inhibits pregnancy during the succeeding season. The occurrence and significance of nursing-period fasting in the Phocidae requires much more investigation. It has been proved to occur only in *Monachus schauinslandi* and *Leptonychotes weddelli;* the latter breeds annually (Mansfield, 1958). In bearded seals, *Erignathus barbatus,* pregnancies do not occur in succeeding years (McLaren, 1958). In all other phocids, as far as is known, the ovarian cycle is annual (Laws, 1956). It is of interest to note that *Erignathus* and *Monachus* have a number of traits in common (Scheffer, 1958), traits which are possibly primitive phocid (or pinniped) characteristics.

Sex ratios.—The sex of 55 monk seal pups was determined during the present study period. Among nine pups at Midway Atoll were three males and six females. Among 46 pups at Laysan Island were 26 males and 20 females. Combined with data from the previous season, we have a total of 51 males and 49 females. No important new data have been obtained on adult and subadult sex ratios.

Growth rates and age groups.—Weights and measurements of three newborn monk seal pups were obtained this season (Table 7). Some evidence on growth rates was obtained by observations on two seals tagged a year ago as yearlings at Midway Atoll:

MS-3, a male tagged as a yearling on 5 March 1957, weighed 46.3 kg. and measured 129 cm. in total length, tip of nose to tip of tail. On 22 March 1958, his weight was visually estimated at 90–115 kg., and his length at 170–180 cm.

MS-4, a female tagged as a yearling on 5 March 1957, weighed 41.7 kg. and measured 130 cm. in total length. On 20 April 1958, her weight was visually estimated at approximately 80 kg., and her length was measured with a steel tape, as she lay sleeping on the sand, at 150 cm.

From the above data, it appears that growth can be quite rapid, but that there is considerable individual variation in this respect.

As stated in the earlier paper, it is not possible to distinguish age groups, other than pups, with any certainty during aerial counts. However, I was able to make ground counts of the age-group composition of the seal populations at Kure Atoll and at Laysan Island (Table 8). No satisfactory age-group count could be obtained at Midway this season. Monk seals are readily segregated into four size groups: pups, yearlings, subadults (all animals two years old and older which have not attained adult size), and adults. Comparing the 1957 with the 1958 totals, there is not more than 2 per cent difference in the proportion of any age group to the total population.

TABLE 8.—*Age-group composition of two populations of Hawaiian monk seals, 1958*

AGE GROUP	KURE ATOLL		LAYSAN ISLAND		TOTAL	
	number	per cent	number	per cent	number	per cent
Adults	107	76	210	65	317	68
Subadults	8	6	53	16	61	13
Yearlings	2	2	17	5	19	4
Pups	22	16	46	14	68	15
TOTALS	139	100	326	100	465	100

These age-group counts of seals cannot be taken as an indication of the actual proportion of each age group in the population. Rather, they are an indication of the number of seals hauled out on land at a given time. They do, however, bring out two facts: (1) The group classed as "subadults" averages almost as large as, and in some cases is larger than, the pup class. It is extremely unlikely that all the subadults were counted, and it is also inconceivable that no mortality occurs between weaning and the age of two years. Both of these factors would reduce the real or apparent size of this age group. Therefore, it must be concluded that the "subadult" group consists not only of the two-year age group but must also include at least some of the three-year (and older?) age group. (2) The few yearling seals in these counts indicate that they spend much less time on land than do older animals. This is also apparent from the rates of repeat observations of tagged animals (Table 9); the repeat rate for yearlings (i. e., animals tagged as pups the previous year) is only half (12 per cent) that for subadults and adults combined (24 per cent).

In addition to pups and yearlings, a two-year, a three-year, and an adult (four-year-plus) age class may prove to be distinguishable on the basis of average size, although there will be considerable overlap in extreme measurements. It is apparent that monk seals grow more slowly than their Antarctic relatives, the Weddell seals, *Leptonychotes weddelli*, and the crabeater seals, *Lobodon carcinophagus*, which attain adult body size in one year (Bertram, 1940).

TABLE 9.—*Repeat observations of tagged Hawaiian monk seals at Kure Atoll, Midway Atoll, and Laysan Island*

AGE GROUP (age when tagged)	NO. TAGGED, 1957	OBSERVED, 1958	
		number	per cent
Adults and subadults	10	2	20
Yearlings	7	2	29
Subtotal	17	4	24
Pups	42	5	12
TOTAL	59	9	15

Mortality rates.—Mortality rates in adult monk seals appear to be low. Only one dead adult was found during the 1957–58 season—a skeleton in the scrub at the upper edge of the beach on Laysan Island.

An adult seal on Laysan had one hind flipper completely missing, the stump healed. Sharks are the only animals in Hawaiian waters known to be capable of preying on seals. Two species of medium-sized sharks were frequently encountered in the shallow waters close inshore at Laysan. One was a species of "sand shark," *Carcharhinus* sp.; the other was the white-tipped shark, *Triaenodon obesus*, also common at Midway and Kure. Both these sharks seemed to ignore the numerous seals, even the tame newly weaned pups. During June and July, many large tiger sharks, *Galeocerdo cuvieri*, up to four meters in length, entered the shallow lagoons at Kure, Midway, and Pearl and Hermes Reef, apparently attracted by large numbers of fledgling albatrosses (*Diomedea immutabilis* and *D. nigripes*). From the air, I observed them in extremely shallow water only a few meters offshore from beaches and sandspits occupied by seal pups, and swimming in close proximity to seals. There is no evidence that they ever attempt to molest the seals. Hammerhead sharks, *Sphyrna lewini*, are sometimes seen inside the lagoon at Midway. In the deeper waters just outside the reef at French Frigate Shoals, where I observed two seals, there was a large pelagic shark, apparently the mako, *Isurus glaucus*. Any of these larger species are physically capable of attacking monk seals but they must do so only rarely, because the seal population has increased in the presence of a large shark population.

It is interesting to compare the 1957–58 count of adult and subadult seals with the total population count at the close of the previous pupping season (Table 6). Excluding the data from Laysan Island and French Frigate Shoals as not comparable, the apparent mortality rate varied (by atoll) from 1.4 to 8.6 per cent, with a mean of 3.6 per cent. The mean birth rate at the four atolls was 16.6 per cent, representing a net annual increment of 12.3 per cent.

DISCUSSION

An examination of the above data reveals that there is no correlation between population density and reproductive rate, mortality rate, or the net annual increment. These data, together with the historical evidence, indicate that the population is increasing and is not at present limited by density-dependent factors.

It is easy to see how population density may eventually limit further population increase by raising the juvenile mortality rate. The length of the nursing period is determined by the fat stores of the mother, who fasts throughout this period. Weaning apparently takes place when the mother is no longer able to produce milk. The ability of a seal to accumulate fat stores can logically be related to the energy expenditure necessary to obtain a given quantity of food. In more densely populated waters which are "overfished," a pregnant female might be unable to put on much weight prior to parturition. The pups of thinner females are weaned at a younger age and smaller size than are pups of fatter females. They thus have less chance for survival during the critical period following weaning, before they have learned to find their own food efficiently. One pup weaned at an unusually early age at Midway Atoll in the spring of 1957 was not subsequently observed, whereas two of three other pups weaned at a normal age during the same season were known to have survived their first year.

The amount of bottom-living fish and cephalopods on the shallow sandy shoals and coral reefs may be the factor which will eventually limit population growth of the Hawaiian monk seal. Future observations on population size, condition of newly parturient females, length of nursing period, weight of pups at weaning, and mortality of weaned pups, will be necessary to prove or disprove this hypothesis.

SUMMARY

1. In the summer of 1958, the total population of Hawaiian monk seals, *Monachus schauinslandi*, was estimated at 1,350, based on a count of 1,206 (1,037 adults and 169 pups).

2. Eighteen repeat observations of 11 marked seals were made at points 3.6 km. or less from the tagging site.

3. Monk seals seem to feed in shallow waters within the 18-m. depth contour. On this basis, calculated population densities varied from 0.08 to 10.77 seals per 100 ha. of shoal water.

4. Reproductive rates varied from 10.3 to 21.4 live births per 100 adults and subadults. At Midway Atoll, where the seals are subject to human disturbance, 13 known pregnancies in a population of 68 seals resulted in eight live births. Present evidence favors the theory of biennial, as opposed to annual, breeding.

5. Of 100 monk seal pups (including 45 previously reported), 51 were males, 49 females.

6. A two-year-old male and a two-year-old female, tagged a year previously, doubled in weight (46 to ca. 100 kg., and 41 to ca. 80 kg.) and increased in length by 36 per cent and 15 per cent (129 to ca. 175 cm., and 130 to 150 cm.). Apparently most monk seals do not attain full growth until at least four years of age. Age-group classification counts on two populations revealed 14 per cent pups, 5 per cent yearlings, 13 per cent subadults, and 68 per cent adults.

7. Adult mortality is apparently low. Several species of sharks are common, but they seem to pay little attention to seals.

8. The population is increasing and does not now appear to be near the carrying capacity of the range. The size will perhaps be limited eventually by the food supply, which will limit the amount of fat which pregnant females can put on. This will shorten the nursing period of their pups, reducing the pups' chances for survival.

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A SYSTEM ANALYSIS OF THE MARINE ECOLOGY

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Introduction

An ecological problem in fisheries research is that of describing explicitly the complicated interrelationships among population size, recruitment, natural mortality, fishing mortality, and predation habits, among several species at each of several trophic levels. Although several individuals have studied population dynamics (cf. 1, 2, 4, 5), the usual approach has been to consider a single species exclusive of its interaction with other species. In this paper, an attempt is made to study the entire system.

In order to speak in general, let us consider r trophic levels with s_i species in the i-th trophic level. Thus, a variable x_{ij} refers to the measure of the variable x associated with the j-th species in the i-th trophic level; $j=1, 2, \cdots, s_i$; $i=1, 2, \cdots, r$. It is recognized that this classification system is somewhat arbitrary. In general the successive trophic levels are occupied by plants, herbivors, and carnivors, with whatever sub-classifications are necessary for the study of species of particular interest. The number of trophic levels and sub-levels in such a classification might be in the neighborhood of six. The species whithin each trophic level may be classified according to similarity of eating habits, i. e. those which feed on essentially the same prey would be classified together. The number of species within each trophic level in such a classification might be in the neighborhood of three or four.

In addition to this general problem of describing an entire system, there is a second problem of predicting the effects of external phenomena upon the equilibrium of the system, and perhaps predicting future balances that occur after an external phenomenon has effected an imbalance. By external phenomena I refer to such things as fishing mortality, which constitutes a loss from the system, or epidemics which produce large effects but occur so infrequently as to not constitute a regular part of the system. I hope here to contribute to the solution of both problems.

The fundamental part of the analysis depends upon measuring the mass and/or energy flux from each classification to each other classification The parameters involved must be estimated by a set of simultaneous equations derived from known biological relationships. Two cases will be treated:

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Case I: the system is in equilibrium
Case II: the system is not in equilibrium.

For the first case, recruitment equals mortality in all classifications, so that only the mortality need be considered; the size (in weight) of the populations are constant. For the second case, recruitment does not equal mortality in all classifications and the sizes of the populations must be considered. Various amounts of matter will be postulated as being removed from the system by fishing or other causes and the pattern of probable results will be predicted by the use of Markov chains.

A cross classification of analysis is the consideration of the system based upon the variables:

Case A: the weight of animals (or plants)
Case B: a measure of transmitted energy.

Both have some disadvantages and each provides information not obtainable from the other.

Solutions: Case A-I

The basis on which the complete analysis is constructed assumes the knowledge of parameters π_{ijkl}=the probability that the weight of a random member of the j-th species of the i-th trophic level will be consumed in the given time interval (say a year) by a random member of the l-th species of the k-th trophic level; $i, k=1, 2, \dots r$; $j=1, 2, \cdots, s_i$; $l=1, 2, \dots, s_k$. To standardize such animal weights, a basic unit of "one pound" will be used. At the present time, such parameters are unkown and unestimated; they are unlikely ever to be known exactly. Methods of estimating such parameters are considered in the last section. For the present let us assume that p_{ijkl}, estimates of π_{ijkl}, are available.

For case A-I, the system is in equilibrium so that the weight of animals present in any one year is the same as the weight in any ensuing year.

Let us define a square matrix P, with dimensions $\sum_{i=1}^{r} s_i+1$, whose typical ik-th partition is P_{ik}, a sub-matrix with dimensions $s_i \times s_k$, whose typical element is p_{ijkl}. After the $\sum_{i=1}^{r} s_i$ rows and columns, there is an additional row and column. This last row is the vector

$$[0 \;\; 0 \;\; 0 \cdots 0 \;\; 1]$$

and the last column is composed of elements p_{ijf}, the probability that a pound of the j-th species of the i-th trophic level exits from the system, not to return. "Exit" will here mean that the pound is removed by fishing, but it could as well imply death by disease, radiation, or any other cause except predation. In order to have P a probability matrix, we must have the restriction:

$$(1) \qquad \sum_{k=1}^{r} \sum_{l=1}^{s_k} p_{ijkl}+p_{ijf}=1.$$

Such a restriction is both reasonable and essential from a biological view. The probability p_{ijij} is the probability that the pound stays in its own species (either by remaining untouched or by cannibalism), p_{ijf} is the probability that the pound exits from the system, and all other p's are probabilities that the pound passes from one position in the system to another; thus all possibilities are accounted for and the sum of probabilities over the entire possibility space must equal unity.

P appears as follows:

$$\begin{bmatrix} p_{1111} & p_{1112} & \cdots & p_{111s_1} & p_{1121} & \cdots & p_{11rs_r} & p_{11f} \\ p_{1211} & p_{1212} & \cdots & p_{121s_1} & p_{1221} & \cdots & p_{12rs_r} & p_{12f} \\ \vdots & \vdots & & \vdots & \vdots & & \vdots & \vdots \\ p_{1s_111} & p_{1s_112} & \cdots & p_{1s_11s_1} & p_{1s_121} & \cdots & p_{1s_1rs_r} & p_{1s_1f} \\ p_{2111} & p_{2112} & \cdots & p_{211s_1} & p_{2121} & \cdots & p_{21rs_r} & p_{21f} \\ \vdots & \vdots & & \vdots & \vdots & & \vdots & \vdots \\ p_{rs_r11} & p_{rs_r12} & \cdots & p_{rs_r1s_1} & p_{rs_r21} & \cdots & p_{rs_rrs_r} & p_{rs_rf} \\ 0 & 0 & \cdots & 0 & 0 & \cdots & 0 & 1 \end{bmatrix} \tag{2}$$

Let us define by N the $1\times\left(\sum_{i=1}^{r} s_i+1\right)$ vector of n_{ij}, the number of pounds of the j-th species of the i-th trophic level entering the system for disposition during this time period. Of course the last element is zero, since no life which has left the system may reenter.

There are two types of quantities which are of particular interest: the size of the j-th species at the end of the time period and the total catch (or total pounds lost from the system). The vector NP would give these quantities if the animals were physiologically 100% efficient, i. e. if a pound eaten provided a pound of growth. Since the organisms are not 100% efficient, there results another source of loss of weight from the system in the form of waste products, etc. To account for this loss from the system, the probabilities in P should be weighted. This can be most easily effected by redefining the p_{ijkl} as the probability that a pound from species j of trophic level i will be consumed and fully utilized in growth by a member of species l of trophic level k. To conform to the restriction that the sum of elements of any row be unity, another row and column must be added to P, such that the bottom row vector is

$$[0 \quad 0 \cdots 0 \quad 0 \cdots 0 \quad 0 \quad 1]$$

and the last column vector is the transpose of

$$[p_{11x} \quad p_{12x} \quad \cdots \quad p_{1s_1x} \quad p_{21x} \quad \cdots \quad p_{rs_rx} \quad 0 \quad 1],$$

where

$$p_{ijx}=1-\sum_{k=1}^{r}\sum_{l=1}^{s_k} p_{ijkl}-p_{ijf}.$$

This p_{ijx} represents a second loss to the system, but one which is not utilized by man. The vector N adds one element, a zero, to have dimensions

$1\times\left(\sum_{l=1}^{r} s_r+2\right)$, and appears as :

$$N=[n_{11}\quad n_{12}\quad \cdots\quad n_{1s_1}\quad n_{21}\quad \cdots\quad n_{rs_r}\quad 0\quad 0]. \tag{3}$$

For case A-I in which equilibrium is assumed, the vector N is the set of weights entering the system each time period regardless of losses. Since the weight of a species remaining from the last time period plus this time period's recruitment equals the weight of the species entering this time period, $NP+R=N$ for case A-I, where R is a vector of recruitment quantities.

It should be observed that for case A, P is a patterned matrix in which the greatest number of partitions are null. If P be partitioned into a matrix in which the ik-th partition P_{ik} is the sub-matrix composed of the probabilities that the weight of the i-th trophic level goes to the k-th trophic level, then, assuming the weight of any trophic level is passed on only to the next higher level, P would appear as

$$\begin{bmatrix}
\delta_{jl}p_{ij1l} & P_{12} & O & \cdots & O & P_{1f} & P_{1x} \\
O & \delta_{jl}p_{2j2l} & P_{23} & \cdots & O & P_{2f} & P_{2x} \\
O & O & \delta_{jl}p_{3j3l} & \cdots & O & P_{3f} & P_{3x} \\
\vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\
O & O & O & \cdots & \delta_{jl}p_{s_rjs_rl} & P_{s_rf} & P_{s_rx} \\
O & O & O & \cdots & O & 1 & 0 \\
O & O & O & \cdots & O & 0 & 1
\end{bmatrix} \tag{4}$$

where δ_{jl} is Kronecker's delta. It is obvious that any power of P will be triangular.

One possible application of the analysis thus far presented is the concept of increasing the commercial catch of a particular species or a set of species by exerting fishing pressures in some optimum pattern. Since fishing effort is independent of predation effort (i. e. in the sense that predation effort is fixed in advance of fishing effort, at least for small intervals of time, and the fishing effort is arbitrary to man), and by the restriction of rows summing to unity, a change (increment or decrement) of d_{ij} in p_{ijf} evokes a change in p_{ijkl} of

$$d_{ijkl}=-\frac{d_{ij}\,p_{ijkl}}{\sum_k\sum_l p_{ijkl}+p_{ijx}}, \qquad d_{ijx}=-\frac{d_{ij}\,p_{ijx}}{\sum_k\sum_l p_{ijkl}+p_{ijx}} \tag{5}$$

Then the typical ij-th row of P becomes the vector

$$[(p_{ij11}+d_{ij11})\cdots(p_{ijrs_r}+d_{ijrs_r})(p_{ijf}+d_{ij})(p_{ijx}+d_{ijx})]. \tag{6}$$

The problem now is to choose the d_{ij} such that either the element of NP associated with the total catch per time period or the element $n_{ij}(p_{ijf}+d_{ij})$ for some ij is maximized. The solution for the latter in this case of equilibrium is trivial and ridiculous: increase d_{ij} until $p_{ijf}+d_{ij}=1$, in which case all fish of that species in the ocean are caught, but by the equilibrium restriction the number entering the next time period will be unaffected by the catch, which obviously does not conform to reality. It is apparent that this problem can be more profitably considered in case A–II.

Solutions: Case A-II

The situation in this case is much the same mathematically as in the preceding section, but with alterations as follows. With the restriction of equilibrium dropped, the vector R of recruitment quantities is not specified by N and P, and so must be considered independently.

Recruitment is variously thought by biologists to be related to population size and to be unrelated to population size. Since one female may produce very large number of eggs, the pertinent influences on number of larvae surviving to adulthood seem to be food availability and intensity of predation upon such larvae rather than the initial number hatched. I shall take this view, at least when extremely large population changes are not present, so that R is a vector of random variables independent of N (for large N). R may be written as $R=E(R)+\underset{\sim}{e}$, where $\underset{\sim}{e}$ is a vector of random deviations with zero expectation. Since we are considering essentially a "typical" system interrelationship rather than possible extremes of relationship, we shall take the vector of recruitment each time period to be $E(R)=\dot{R}$.

Taking N as in (3), P as in (4), we have the weight in the various populations at the end of the time period as:

$$N^{(1)}=NP+\dot{R}. \tag{7}$$

In case II, the weight of animals (or plants) entering any given time period is not restricted to be the same as for any other time period, so that it becomes of interest to follow the weight vector through successive time periods. Let us denote by $N^{(n)}$ the weight vector of populations at the end of the n-th time period (i. e. entering the $(n+1)$-th time period). By the usual theory of Markov chains we find

$$N^{(n)}=NP^{n}+\dot{R}\sum_{h=1}^{n}P^{h-1}\ , \tag{8}$$

where $P^{0}\equiv \mathrm{I}$.

To pursue our example of choosing fishing efforts such as to maximize the sum of catches over many years, let us again cause a vector $\varDelta$ of changes d_{ij} as defined in (5) to be effected on the vector of catch probabilities (by changing fishing effort) so that the typical row of P will appear as in (6). The desired solution is obtained by finding $\varDelta$ to maximize one (or a set of) catch weight(s) summed over a desired number of time periods, i. e. maximize $\sum_{h=1}^{n} n_{ij}^{(h)}\ p_{ijf}+d_{ij}$, where $n_{ij}^{(h)}$ is the ij-th element of $N^{(h)}$ and the ij-th species is the species of commercial interest. Here n is a finite integer>0.

Let us now consider the ultimate result of the ecological system as defined. As n becomes large, $N^{(n)}$ approaches an ultimate disposition of weights.

$$N^{*}=\lim_{n\to\infty}\ N^{(n)}=N\lim_{n\to\infty}\ P^{n}+\dot{R}\lim_{n\to\infty}\sum_{h=1}^{n}P^{h-1}. \tag{9}$$

Since P possesses two absorbing states, $\lim_{n\to\infty} P^n$ will go to the form

$$\left[\begin{array}{c|c} O & A \\ \hline O & I \end{array}\right],$$

where A is a $\left(\sum_{i=1}^{r} s_i \times 2\right)$ matrix, the elements of whose rows sum to unity.

However, $\lim_{n\to\infty} \sum_{h=1}^{n} P^{h-1}$ contains P and $\dot{R}P$ has no null elements, which implies that N^* contains no null elements. This implies biologically that so long as an assumption of R with all non-null elements holds, the system will not disintegrate and no species will become extinct.

Implicit in the Markov chain is the assumption of fixed P. This assumption is reasonable for a steady state system which has been observed in isolated cases, but it is obvious that a marked change in relative density of two competing predators will alter the proportion of a prey species being consumed by each, and hence alter elements of P. Thus a more general analysis and prediction will be obtained if we define P_h as a P derived anew at the end of the h-th time period by the methods in the last section, whence (8) alters to

$$N^{(n)} = NP\prod_{h=1}^{n-1} P_h + \dot{R}\left(\sum_{f=1}^{n-1}\prod_{h=f}^{n-1} P_h + I\right). \tag{10}$$

Once a change is effected, and for $N^{(n)}$ as defined in (10), if there exists a positive integer ν such that $|N^{(n+1)} - N^{(n)}| \leq \varepsilon$ for every $n > \nu$, ε an arbitrarily small non-negative quantity, then the system is said to be able to return to equilibrium, and $N^{(n)}$ and P_n define to any desired degree of approximation the new equilibrium.

Solutions: Cases B-I, B-II

In case B, the unit transmitted from one species to another is not the weight of animals, but a more basic measure of energy (and/or matter). In this case, all organic matter may be considered. The diseased fish feeds his parasites and thus is not lost from the system. A fish eats, and produces waste products, which are acted upon by bacteria and are subsequently available as plant nutrients. In a complete analysis of this type, the path of *all* energy transfer is traced so that (except for removal by man) no energy is lost from the system. Heat loss is replaced by sunlight. River discharges are added to the system. Thus, a much more complete analysis is permissible, although the estimation of the probabilities involved will be much more difficult and likely less exact, which will limit the usefulness of this case. In a recent paper, Odum[(8)] discusses some of the variables involved in case B-I, but no attempt at a numerical analysis of the system or a predictive model was made, nor were feedbacks to one part from changes elsewhere in the system included.

Mathematically, P is defined as in (2), since the p_{ijx} are no longer necessary. Furthermore, any species may make a contribution of one sort or another to any other species, so that powers of P are not necessarily triangular.

Derivation of the matrix P

Estimators for the elements of P will be derived for case A. Estimators for case B are similar mathematically, but depend on more complex physiological measurement, which is not currently feasible.

Assumption 1. Foraging effort e_{ij} of species ij (or, more generally, the volume of water exposed to the predator) is a function of the density of predator ij.

Assumption 1 a. e_{ij} is approximately linear with n_{ij} with boundary condition (0, 0) and slope m_{1ij}, i.e. $e_{ij} \doteqdot m_{1ij} n_{ij}$.

Assumption 1 will be considered to be self-obvious; Assumption 1a should be justified. Consider separately predation by non-schooled and schooled animals. If the animals are randomly placed and non-schooled, and the measure of density is the continuous variate weight, then the volume of water exposed to a fixed number n_{ij} of species ij as the animals grow in weight will be constant or increasing linearly with a very small slope as the animals are non-self-mobile or self-mobile respectively. When an additional member of the species is recruited, the function e_{ij} takes a sudden increase or step. A line constructed through the steps represents the average function e_{ij} on n_{ij}, which illustrates that the scouting effort is approximately linear with the weight of individuals. The deviations from this line are very small. The slope m_{1ij} will be determined by the scale on the e_{ij}-axis. If the animals are schooled, the situation is precisely the same, except that the step represents the addition of a school rather than a single individual. The magnitude of the increment or step will be greater in each instance, but is still quite small relative to the weight of animals in the ocean.

Assumption 2. The weight of prey $i-1$, l consumed by ij, $n_{(i-1)le_{ij}}$, increases linearly with scouting effort, e_{ij}, with boundary condition (0, 0) for fixed prey density.

Then since a linear function of a linear function is linear,

$$n_{(i-1)le_{ij}} = m_{2ij} n_{ij}, \tag{11}$$

for fixed density of prey species $i-1$, l.

By analogous reasoning, if the prey density $n_{(i-1)l}$ of species $i-1$, l of predation interest to species ij is allowed to vary and n_{ij} is held fixed, we may arrive at

Assumption 3. The weight of prey $i-1$, l consumed by ij, $n_{(i-1)le_{ij}}$, increases linearly with an increase in density of $i-1$, l, $n_{(i-1)l}$, with boundary condition (0, 0) for fixed density of predator and fixed scouting effort.

Then

$$n_{(i-1)le_{ij}} = m_{3(i-1)l} n_{(i-1)l}, \tag{12}$$

for fixed n_{ij}.

Now if both n_{ij} and $n_{(i-1)l}$ are allowed to vary,

$$n_{(i-1)le_{ij}} = f(n_{ij},\ n_{(i-1)l}),$$

where $f_1(n_{ij} \mid n_{(i-1)l}) = m_{2ij}\, n_{ij}$ and $f_2(n_{(i-1)l} \mid n_{ij}) = m_{3(i-1)l} n_{(i-1)l}$.

Then since

$$f(n_{ij},\ n_{(i-1)l}) = f_3(n_{ij}) f_2(n_{(i-1)l} \mid n_{ij}) = f_4(n_{(i-1)l}) f_1(n_{ij} \mid n_{(i-1)l}),$$

we substitute to obtain

$$m_{3(i-1)l} n_{(i-1)l} f_3(n_{ij}) = m_{2ij} n_{ij} f_4(n_{(i-1)l}),$$

from which

$$f_3(n_{ij}) \propto n_{ij} \quad \text{and} \quad f_4(n_{(i-1)l}) \propto n_{(i-1)l}.$$

Then

$$n_{(i-1)le_{ij}}=f(n_{ij},\ n_{(i-1)l})\propto n_{ij}n_{(i-1)l}=b_{(i-1)lij}n_{ij}n_{(i-1)l} \tag{13}$$

where $b_{(i-1)lij}$ is an arbitrary scale parameter.

Denote by μ_{ij} an estimate of the mortality rate per time period of species ij (excluding cannibalism). Suppose these quantities are available (estimation techniques are largely biological and will not be discussed here). Denote by y_{ij} an estimate of the average diet in weight of species ij. These diets are estimable from growth curves of species plus knowledge of their physiological efficiencies. Also the p_{ijx} can be found physiologically, which will permit estimation of p_{ijkl} when n_{ij} and n_{ijekl} are found. Denote by v_{ijkl} an estimate of the proportion of diet of kl represented by ij. These diet quantities are estimable by stomach content analysis of kl or similar biological techniques. Denote by c_{ij} the catch or its estimate of ij per time period, which is a matter of record. Then the following equations emerge:

$$\mu_{(i-j)l}n_{(i-1)l}-\sum_{j=1}^{si}n_{(i-1)le_{ij}}-c_{(i-1)l}=0 \tag{14}$$

$$(1-\mu_{(i-1)l})=p_{(i-1)l(i-1)l} \tag{15}$$

$$n_{ij}v_{(i-1)lij}y_{ij}=n_{(i-1)le_{ij}} \tag{16}$$

$$\sum_{i=1}^{r}\sum_{j=1}^{si}n_{(i-1)le_{ij}}+(1--y_{(i-1)l})n_{(i-1)l}-n_{(i-1)l} \tag{17}$$

$$b_{(i-1)lij}=n^{-1}_{(i-1)l}n^{-1}_{ij}n_{(i-1)le_{ij}} \tag{18}$$

$$p_{(i-1)lij}=n^{-1}_{(i-1)l}n_{(i-1)le_{ij}}(1-p_{ijx}) \tag{19}$$

$$p_{(i-1)lf}=n^{-1}_{(i-1)l}c_{(i-1)l}. \tag{20}$$

Solving this set of equations, we now have the matrix P in addition to estimates of the total weight of animals of the various species.

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ABSTRACTS

An ecological problem in fisheries research is that of describing explicitly the complicated interelationships among population size, recruitment, mortality, predation habits, and fishing effort among the several species at each of several trophic levels. A second problem is that of predicting the effects of varied fishing efforts, epidemics and other external phenomena upon the equilibrium of the system, and perhaps predicting future balances that occur after an external phenomenon has effected an imbalance. This paper is a first effort at providing a solution to both problems.

The fundamental part of the analysis depends upon measuring the amount of each classification contributed to each other classification as nutrient, and is in some ways similar mathematically to Leontief's economic input-output analysis. The parameters to be utilized must be estimated by a set of simultaneous equations derived from known biological relationships. Two cases are treated: the system is in equilibrium; system is not in equilibrium. For the first case recruitment equals mortality in all classifications, so that only the mortality is analyzed: the size of the population is static. For the second case, the entire population must be considered, and additional classifications, e.g. the animals left alive, the amount of recruitment, etc., are added. The additional classifications cause mathematical problems, which are discussed.

A cross-classification of analysis is the consideration of the system based upon a variable: the weight of animals or plants; and based upon a variable: a measure of transmitted energy. Both have some disadvantages and each provides information not obtainable from the other. Both are presented and discussed.

In order to consider the second problem, i.e. prediction of change in the system, various amounts of animals are postulated as being removed from the system due to fishing effort or other causes, and the pattern of probable results is predicted by the use of a modified Markov chain, along with expected results. The essential problem mathematically is that the stochastic matrix must be redefined after each time period in order to admit a feedback effect.

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A NEW METHOD FOR ESTIMATING PARAMETERS FOR THE GOMPERTZ GROWTH CURVE

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A New Method for Estimating Parameters for the Gompertz Growth Curve

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1. Introduction

There are three major uses for biological growth curves:—

(a) to compare differences in growth phenomena and perhaps conduct tests of these differences;
(b) to describe the changes in growth phenomena under varying conditions of environment and/or heredity;
(c) to describe the ideal growth phenomenon (that which is expected to be typical);

(a) has been extensively investigated in papers by WISHART (1938) and RAO (1958); (b) usually involves a comparison of growth phenomena for each of the varying conditions and hence reduces to (a). When (b) is purely descriptive, it involves initiating the investigation from given conditions or assumptions and obtaining the curve in terms of these conditions. Item (c) starts with empirical data and attempts to obtain a curve that will exactly describe the growth phenomenon. This paper is concerned with (c).

A recent paper by RICHARDS (1959) presents a general growth curve based on four parameters which admirably relates the different curves that have been studied in the past. Although this general curve is of interest when in the early stages of growth study, it does add an additional parameter to be estimated. The present paper is concerned with the subordinate problem of estimating the remaining three parameters given the fourth has been chosen such that the growth curve takes on the form of the Gompertz curve.

Growth curves are almost always asymmetric (BRODY, 1945), so that while several workers have investigated symmetric curves, their work is usually inappropriate for purpose (c). The curve of VON BERTALANFFY (1938) has been given particular attention lately (e. g. BEVERTON and HOLT, 1957), but it is an exponential curve everywhere concave downward so is also inappropriate for purpose (c). The only asymmetric sigmoid curve cited in the literature is that of GOMPERTZ (1825). The Gompertz has classically provided good fits, its parameters are shown (WEYMOUTH and MCMILLIN, 1930) to relate to biological considerations, and it has rather extensive applications including as growth of individual animals and plants, growth of animal and microorganic populations, regeneration of tissue, mortality, chemical reactions (catalytic, temperature, etc.) (THOMPSON, 1948), engineering applications (DAVIS, 1955), and psychological learning curves.

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Currently the use of the Gompertz suffers from lack of techniques to estimate its parameters. BRODY (1945) infers series expansion is necessary, stating that it is therefore of little practical use. It is the purpose of this paper to derive methods of estimating the Gompertz parameters.

For the Gompertz function

$$y = a\,b^{c^t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

it can be easily shown that, for maximum likelihood estimation, no unique solution exists for *a* and *b* and no finite solution exists for *c*. No other method of obtaining estimators of the general parameters in terms of the independent variable has been found by the author or has been found in the literature. For the special case in which *a* is unity, a "log log" transformation will yield a function of *y* linear with a function of *t* and the usual techniques of linear estimation may be employed to find estimators of *b* and *c*; such a special case is not usual.

There is another way to obtain estimators. The Gompertz function is single-valued and continuous in both the independent and dependent variables. Therefore, the dependent variable, *y*, may be employed exclusively in obtaining estimators of parameters. Solutions in the dependent variable have been obtained and are given here.

One solution was obtained by SCHULER and is given in DAVIS (1955) for problems associated with chemical engineering. A second solution, somewhat more general, was obtained by the author and is given in two aspects, viz., a long and a short method. SCHULER's method is given first. A derivation and a proof necessary to the author's method follow and then his long and short methods.

2. Schuler's Method

Suppose there are $3n$ values of t for equation (1) such that $t_{i+1} - t = t_{j+1} - t_j$, $i, j = 1, 2, \ldots, 3n$. Let (1) be reduced to the form

$$\log y_t = \log a + c^t \log b. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Consider the quantities

$$S_1 = \sum_{t=1}^{n} \log y_t = n \log a + \left(\sum_{t=1}^{n} c^t\right) \log b \quad \ldots\ldots\ldots\ldots(3)$$

$$S_2 = \sum_{t=n+1}^{2n} \log y_t = n \log a + \left(\sum_{t=n+1}^{2n} c^t\right) \log b \quad \ldots\ldots\ldots\ldots(4)$$

$$S_3 = \sum_{t=2n+1}^{3n} \log y_t = n \log a + \left(\sum_{t=2n+1}^{3n} c^t \right) \log b \ldots\ldots\ldots\ldots(5)$$

It can be easily shown that

$$\frac{S_1 - S_2}{S_2 - S_3} = \frac{1}{c^n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

and that

$$\log b = \frac{S_1 - S_2}{\sum_{t=1}^{n} c^t (1 - c^n)}$$

$$= \frac{(S_1 - S_2)(1 - c)}{(1 - c^n)^2} \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

from which estimates of c and b can be found. If (2) is solved for log a and the appropriate functions of the estimates of b and c substituted, there is obtained the expression

$$\log a = \frac{1}{n} S_1 - \frac{S_1 - S_2}{1 - c^n} \ldots\ldots\ldots\ldots\ldots\ldots(8)$$

from which an estimate of a may be obtained.

It can be seen that SCHULER's technique exhibits certain disadvantages. The number of observations must be $3n$, n a positive integer, and the independent variable values must be integers obtained at equal intervals. $3n$ logarithms must be obtained. Aside from restrictions on the independent variable observations, it is seen that, while c is a function of all three sums, a and b are obtained as functions of the first two sums only. This is a waste of data and may introduce bias. Furthermore, using the sums representing the lower part of the curve (concave upward), the center part (relatively straight), and the upper part (concave downward) as if they were three random observations suggests the introduction of further bias.

3. A Basic Derivation

Consider any three pairs of observations, say y_i, y_{i+j}, and y_{i+k}, with the respective integral t-values, i, $i + j$, and $i + k$, $k > j > i > 0$. From (1),

$$\frac{y_{i+k}}{y_{i+j}} = \frac{a\, b^{c^{i+k}}}{a\, b^{c^{i+j}}} = b^{c^i (c^k - c^j)} \ldots\ldots\ldots\ldots\ldots\ldots(9)$$

Similarly,

$$\frac{y_{i+j}}{y_i} = b^{c^i (c^j - 1)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

Then in general,

$$\frac{\log \frac{y_{i+k}}{y_{i+j}}}{\log \frac{y_{i+j}}{y_i}} = \frac{c^i (c^k - c^j) \log b}{c^i (c^j - 1) \log b} = (c^k - c^j)(c^j - 1)^{-1} \ldots\ldots(11)$$

Frequently k can be chosen such that $k = 2j$. In this case,

$$\frac{\log \frac{y_{i+k}}{y_{i+j}}}{\log \frac{y_{i+j}}{y_i}} = c^j \quad \ldots\ldots (12)$$

Equations (11) or (12) may be solved for c, since the left-hand side of the equation is a numerical value. In general, $0 < c < 1$.

The estimate for c can be substituted for c in the following equations to obtain an estimate for b. In general,

$$\frac{\log^2 \frac{y_{i+k}}{y_{i+j}}}{\log \frac{y_{i+j}}{y_i}} = \frac{c^{2i}(c^k - c^j)^2 \log^2 b}{c^i (c^j - 1) \log b} = \frac{c^i (c^k - c^j)^2 \log b}{c^j - 1} \quad \ldots\ldots (13)$$

or

$$\log b = \frac{(c^j - 1) \log^2 \frac{y_{i+k}}{y_{i+j}}}{c^i (c^k - c^j)^2 \log \frac{y_{i+j}}{y_i}} \quad \ldots\ldots (14)$$

In the special case in which $k = 2j$,

$$\log b = \frac{\log^2 \frac{y_{i+k}}{y_{i+j}}}{c^{i+k}(c^j - 1) \log \frac{y_{i+j}}{y_i}} = \frac{\log \frac{y_{i+k}}{y_{i+j}}}{c^{i+j}(c^j - 1)} \quad \ldots\ldots (15)$$

An estimate of b may be obtained from (14) or (15). In general, $0 < b < 1$.

The estimates for c and b may now be substituted for c and b in the following equations to obtain an estimate for a.

$$\log (y_i + y_{i+j} + y_{i+k}) = \log a + \log (b^{c^i} + b^{c^{i+j}} + b^{c^{i+k}}) \ldots\ldots (16)$$

or

$$\log a = \log (y_i + y_{i+j} + y_{i+k}) - \log (b^{c^i} + b^{c^{i+j}} + b^{c^{i+k}}) \ldots\ldots (17)$$

from which an estimate for a may be found.

Now we have estimates for a, b, and c from three and only three observations.

4. A Proof

We wish to prove that the first two moments of the Gompertz function exist. For convenience in series expansion, let us choose the Gompertz form used by WEYMOUTH and MCMILLIN (1930), viz.,

$$y = Ae^{Be^{-Cx}} \quad \ldots\ldots (18)$$

We lose no generality if we let $0 \leq x < t < \infty$.

$$\mu = \int_0^t xAe^{Be^{-Cx}} dx$$

$$= A\int_0^t x\left(1 - Be^{-Cx} + \frac{B^2}{2!}e^{-2Cx} - \ldots\right)dx$$

$$= A\int_0^t \sum_{i=0}^{\infty}(-1)^i \frac{B^i}{i!}\, x\, e^{-iCx}\, dx$$

$$= A\sum_{i=0}^{\infty}(-1)^i \frac{B^i}{i!}\int_0^t x\, e^{-iCx}\, dx$$

$$= A\sum_{i=0}^{\infty}\frac{B^i(-1)^i}{i!\, i^2C^2}\left[e^{-iCt}(-iCt - 1) + 1\right] \ldots\ldots\ldots\ldots\ldots\ldots (19)$$

But the alternating infinite series (19) is less term by term than the series expansion of e^B, which is absolutely convergent. Therefore (19) is absolutely convergent and μ exists.
Similarly,

$$\mu_2' = \int_0^t x^2\, Ae^{-Be^{-Cx}}\, dx$$

$$= A\sum_{i=0}^{\infty}\frac{(-1)^i B^i}{i!}\left[\frac{t^2 e^{-iCt}}{-iC} + \frac{2}{iC}\int_0^t x\, e^{-iCx}\, dx\right]$$

$$= A\sum_{i=0}^{\infty}\frac{(-1)^i B^i}{i!}\left[\frac{t^2 e^{-iCt}}{-iC} + \frac{2}{i^3C^3}\left\{e^{-iCt}(-iCt - 1) + 1\right\}\right]$$

$$= A\sum_{i=0}^{\infty}\frac{(-1)^{i+1} B^i}{i!\, iC}\left[e^{-iCt}\left\{(t + iC)^2 + 2 - 2e^{iCt} - i^2C^2\right\}\right] \ldots (20)$$

Let a_i denote the ith term of (20). There exists a number N such that, whenever $i > N, |a_i| < \mu_i$, where μ_i is the ith term of the absolutely convergent series e^B. Thus (20) is an absolutely convergent series and μ_2' exists.

Thus the first two moments of the distribution (18) exist.

5. The Long Method

The author's method of fitting parameters to the Gompertz equation involves one restriction it shares with SCHULER's method: the abscissa values must be integers. However, the restriction of equal intervals is absent so that this restriction can be circumvented by a scale transformation. The sample size will be $3n \overset{0}{\pm} 1$, which may be read "$3n$, $3n$ increased by one, or $3n$ decreased by 1". The procedure in paragraph 3 above may be utilized n times. This may necessitate one observation, which may be chosen randomly, being used twice or being rejected from use. Utilization of the procedure n times will yield n estimates of a, b, and c.

If we average these n estimates for each parameter, we obtain a new set of estimates for a, b, and c, say a_0, b_0, and c_0. In paragraph 4, it was shown that the first two moments exist for the Gompertz function. a, b, and c are functions, always finite for finite $y \neq 0$, of the observed y's, rather than of the observed t's as in usual estimation procedure. Thus the first two moments also exist for the distributions of each a, b, and c, by SLUTSKY's theorem (CRAMER, 1946). The existence of these moments permits the use of the central limit theorem. Thus each of a_0, b_0, and c_0 are distributed normally with distribution mean equal to the respective parameters. We have, then, that our estimates, a_0, b_0, and c_0, approach the respective parameters stochastically as n increases. For large n this method is legitimate and should yield much more accurate estimates than does SCHULER's technique. It is, however, a lengthy procedure for large n.

If measures of accuracy of estimation are desired, confidence intervals on the estimates could be obtained by use of the central limit theorem.

6. The Short Method

If a rapid estimation is desired, any three pairs of the observations may be chosen and the procedure of paragraph 3 above followed to obtain estimates for a, b, and c. If the error deviation of the observations from the true relationship between the variables is not large, this estimation should be adequate for most cases.

How the three observations to be used will be chosen is arbitrary. It is suggested that the first datum be chosen randomly from the first third of the number of observations and the remaining two data be chosen from the second and third thirds respectively such that $k = 2j$.

7. The Estimation of Age and Growth of Yellowfin Tuna

A paper by MOORE (1951) is concerned with the estimation of age and growth of yellowfin tuna. He obtains size (modal length) at a certain stage in growth and arbitrarily designates this size as associated with age N. Then he obtains age for other sizes in terms of $N + 1$, $N - 2$, etc. He postulates that a Gompertz growth curve represents the modal growth of the population. He extrapolates the spawning period from the condition of the gonads and from this extrapolates the time of birth. The curve is apparently a freehand sketch.

Using the techniques of the present paper, it is possible to obtain estimates of the parameters of a Gompertz equation from the data points without age being known.

Let us analyse MOORE's data using the techniques of this paper. Let the time units t be months and let us arbitrarily designate the first data point as $t = 1$. Then the 25 data points are given as in Table 1.

Let us postulate that a Gompertz curve represents the relationship between the length in centimetres, y, and the age of the yellowfin tuna in months, t. Since we chose an arbitrary $t = 1$, the origin will have to be moved d units along the t-axis in order for the resultant curve to coincide with the data points. Thus, the postulated function is of the type

$$y = a\,b^{c^{(t+d)}} \qquad \text{(21)}$$

After obtaining estimates for the parameters in (21), we have the time of birth (or hatching) and may find the length at any age in months after birth.

Table 1

Modal values of lengths associated with arbitrary age designation for yellowfin tuna taken in Hawaiian waters

t (age in months)	y (length in cm)	t (age in months)	y (length in cm)
1	47·2	28	138·7
2	47·2	29	140·3
9	69·7	30	138·7
12	93·0	31	146·3
13	93·0	34	156·4
20	125·3	35	152·1
21	120·2	38	152·4
22	125·3	39	158·2
23	130·1	41	156·4
24	142·6	43	162·5
25	134·5	44	163·1
26	138·7	53	167·6
27	138·7		

Following the technique of this paper, we could use either the long or the short method. It was not shown how rapidly the estimates by the long method converge to the parameters. The author feels intuitively that eight triplets of observations is an inadequate number for convergence and therefore the short method which is considerably simpler numerically is appropriate.

All sets of triplets y_i, y_{i-j}, and y_{i+k} having the property $k = 2j$ were obtained and one was chosen randomly. This triplet contained the data points (13, 93·0), (27, 138·7), and (41, 156·4). From (12),

$$c^{14} = \frac{\log \dfrac{156{\cdot}4}{138{\cdot}7}}{\log \dfrac{138{\cdot}7}{93{\cdot}0}} = \frac{\log 1{\cdot}1276}{\log 1{\cdot}4914} = \frac{0{\cdot}05215}{0{\cdot}17359} = 0{\cdot}30042 \quad \ldots\ldots\ldots (22)$$

$$\log c = \frac{1}{14} \log 0{\cdot}30042 = \frac{1}{14} (-\ 0{\cdot}52227) = -\ 0{\cdot}03730 \quad \ldots\ldots\ldots (23)$$

$$c = 0{\cdot}91770 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (24)$$

From (15),

$$\log b = \frac{\log \dfrac{y_{41}}{y_{26}}}{c^{41} - c^{27}} = \frac{0{\cdot}05215}{0{\cdot}02956 - 0{\cdot}09838} = -\ 0{\cdot}75777 \quad \ldots\ldots\ldots (25)$$

$$b = 0{\cdot}17468 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (26)$$

From (17),

$$\begin{aligned} \log a &= \log (y_{13} + y_{27} + y_{41}) \\ &\quad - \log (\text{anlog}\ c^{13} \log b + \text{anlog}\ c^{27} \log b + \text{anlog}\ c^{41} \log b) \\ &= \log 388{\cdot}1 - \log (0{\cdot}56480 + 0{\cdot}84226 + 0{\cdot}94972) \\ &= 2{\cdot}58894 - 0{\cdot}37232 = 2{\cdot}21662 \quad \ldots\ldots\ldots (27) \end{aligned}$$

$$a = 164{\cdot}78 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (28)$$

Table 2

Some age and size relationships for yellowfin tuna obtained from equation (30)

t (months after birth)	y (cm length)	t (months after birth)	y (cm length)
0	0·2	35	117·1
5	1·8	40	132·0
10	8·9	45	142·6
15	24·6	50	150·0
20	50·5	60	158·3
25	73·6	70	162·0
30	97·5	80	163·6

It may be noted that

$$\lim_{t \to \infty} a\, b^{c^{(t+d)}} = \lim_{v \to 0} a\, b^{v} = a \quad \ldots\ldots\ldots\ldots\ldots\ldots (29)$$

so that 164·78 cm is the estimate of the asymptotic modal maximum of growth.

Inspection of the curve obtained from the estimates (24), (26), and (28) showed that if the origin were translated 16 units to the left, the curve would pass satisfactorily through the data points. This gives 16 as an estimate of d. (21) then becomes in this specific case,

$$y = (164{\cdot}78)\,(0{\cdot}17468)^{(0{\cdot}91770)^{(t+16)}} \quad \ldots\ldots\ldots\ldots\ldots (30)$$

Table 2 gives y for several values of $t' = t + 16$ (t' is the age after birth). It is seen that a 6 year-old yellowfin will have very nearly attained his maximum possible growth. Also, the size of the yellowfin at birth is given as 0·2 cm, which is quite reasonable.

Figure 1 shows the curve MOORE obtained for his data with the curve (30) superimposed. (30) gives birth about five months earlier than does MOORE. It is apparent from inspection that (30) yields as good a fit, despite having been obtained from only three data points.

Summary

The problem is to obtain an expression for the ideal growth curve of an organism (or other phenomenon) given a set of observations. Growth curves are discussed and the Gompertz curve posited. Methods for obtaining estimates of the Gompertz parameters are compared. Two new methods, both based on the same technique, are given. The long method provides estimates which converge in probability to the parameters as the sample size grows large, but involves a great deal of numerical calculation. The short method gives rapid and simple first approximations to the parameters, but is considerably less accurate.

A numerical example is given. Length data on yellowfin tuna from Hawaiian waters are analysed and an estimate of the growth curve is obtained; an estimate of the time of birth is also obtained so that length can be found as a function of age.

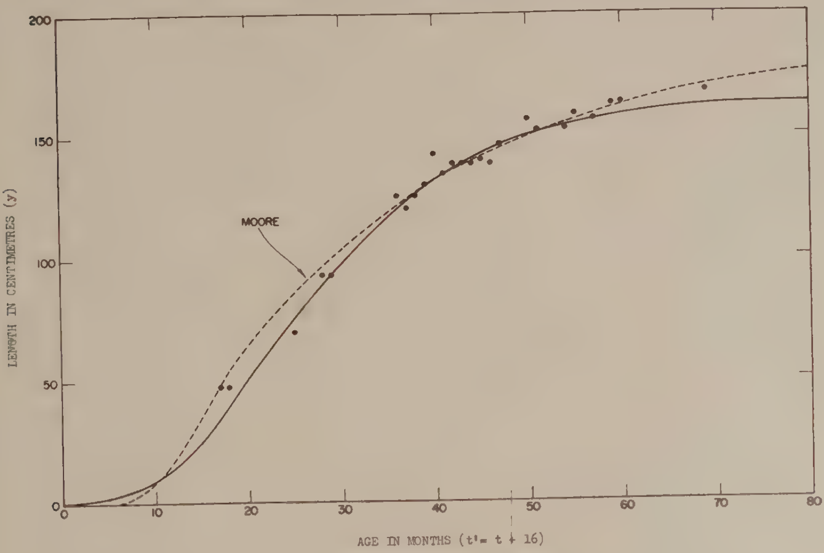

Figure 1. Growth curves of yellowfin tuna after MOORE (1951) and by the method of this paper with actual modal values in length superimposed.

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ANDELSBOGTRYKKERIET I ODEN

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Records Of Marine Turtles In Maine

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Sea turtles are uncommon along the Maine coast, yet they are not as rare as one would believe from reading newspaper accounts of their captures. Newspapers often refer to the large marine turtles as "strange monsters," and, as Babcock (1945) stated, newspaper reporters often quote "veteran fishermen" as saying that they have never heard of or seen such animals before. The purpose of this paper is to supplement the existing Maine marine turtle records. A source for some of the records presented here is the newspaper clipping file of the late Arthur H. Norton, former curator of the Portland Society of Natural History.

There are five species of marine turtles that live in the western North Atlantic. They are all warm-water animals. The green turtle (*Chelonia mydas mydas* Linnaeus) and the hawksbill turtle (*Eretmochelys imbricata imbricata* Linnaeus) have not been reported from Maine. The leatherback (*Dermochelys coriacea coriacea* Linnaeus) has been recorded in Maine 15 times, and we are here reporting 15 more occurrences. Records for the loggerhead (*Caretta caretta caretta* Linnaeus) and ridley (*Lepidochelys olivacea kimpi* Garman) are presented here for the first time.

In the northwest Atlantic the northern limit of the range of the leatherback turtle is Nova Scotia (Schmidt 1953, and Logier and Toner 1955). Squires (1954) heard of a large "leathery" turtle that was landed on the Newfoundland coast, and, if accepted as valid, this record would extend the range to Newfoundland. Bleakney (1958) believed that the species is rare in both Nova Scotia and Newfoundland. Babcock (1919, 1939, and 1945) has reported the appearances of leatherbacks in New England over a long period. As Babcock (1945) mentioned, the huge size of the leatherback (specimens weighing more than 1,000 pounds have been reported) is of dramatic interest, and captures are usually recorded; however, smaller species of sea-turtles may go unnoticed.

Table 1 shows the existing records. The table is divided into two parts: authenticated records (15) and probable records (15). Babcock's records that we were unable to confirm have been put in the

Date	Source of Information	Locality	Finder	Size[2]
Sept. 21, 1919	Portland Telegram	Southwest of Seguin	Swordfishing vessel *Fannie Belle*	7 feet 1,600 lb.
Aug. 2, 1926	Portland Evening Express	Off Casco Bay	Tunafisherman B. Johnson	1,000 lb to 1,200 lb.
Sept. 9, 1928	Portland Press Herald	Between Cape Elizabeth and Portland Lightship	Lobsterfisherman Herbert Doughty	1,000 lb.
Sept. 20, 1928	Portland Evening Express	South Portland	Animal washed ashore	5 feet 500 lb. to 600 lb.
Aug. 4, 1932	Portland Evening Express	Off Cod Lodge, Casco Bay	Tunafisherman Harold Ricker	800 lb.
Aug. 1, 1937	Portland Press Herald	Isle au Haut	Lobsterfisherman Goodwin Grant	1,000 lb.
Aug. 8, 1937	Portland Evening Express	Halfway Rock, Casco Bay	Sportfisherman Harry Clak	6 feet 600 lb.
Aug. 25, 1937	Portland Press Herald Whiteley (1938) Babcock (1939)	Off Seguin	Tunafisherman Willis Brewer	8½ ft. 1,150 lb.
Aug. 1, 1939	Babcock (1945) Personal observation (L.W.S.)	Off Boothbay Harbor	Tunafisherman	990 lb.
July 29, 1940	Babcock (1945) Personal observation (L.W.S.)	Off New Harbor	Tunafisherman	-
July 22, 1950	Portland Press Herald	Criehaven	Lobsterfisherman Russell Simpson	1,000 lb.
Aug. 10, 1957	Portland Press Herald Ray and Coates (1958)	Vinalhaven Island	Lobsterfisherman Carroll Brown	8 feet 635 lb.[3]
Aug. 18, 1957	Personal observation (L.W.S.)	Bantam Bouy, Boothbay	Sportsfisherman Pat Elderkin	
Aug. 28, 1958	Portland Press Herald Personal observation (C.J.P.)	Lumbo Buoy, Casco Bay	Sportfishermen Clifton and John Morgan	7 feet 1,100 lb.
Aug. 6, 1959	Personal observation (L.W.S.)	Near Portland Lightship	Sportfishermen Clifton Wilson and Larrabee	7½ ft.[3]

Date	Source of Information	Locality		
1866	Babcock (1919)	Maine coast	Unknown	—
1877	Babcock (1919)	Naskeag Pt.	Unknown	—
Sept. 1878	Babcock (1919)	Cape Elizabeth	Unknown	—
July 22, 1885	Portland Press Herald Babcock (1919)?	Halfway Rock, Casco Bay	Swordfishing vessel *Dreadnaught*	7½ feet 1,000 lb.
Aug. 4, 1887	Portland Advertiser	Off Portland	Trawl fisherman	8½ feet 1,400 lb.
Aug. 19, 1908	Portland Evening Express Babcock (1919)?	Off Cape Newagen	Swordfishermen John Snowman and Dexter Nelson	9 feet 1,500 lb.
Aug. 21, 1908	Boston Globe Babcock (1939)?	S.W. of Wood Island	Swordfishing vessel *Sea Foam*	1,200 lb.
Aug. 24, 1908	Portland Evening Express	S.W. of Boon Island	Swordfishing vessel *St. Paul*	10 feet 1,500 lb.
1909	Babcock (1919)	Near Portland	Unknown	—
1920	Babcock (1939)	Off Old Orchard Beach	Unknown	—
1934	Babcock (1939)	Off Rockland	Unknown	-
Aug. 3, 1944	Babcock (1945)	Pemaquid Pt.	Unknown	— -
July 25, 1948	Babcock (1945)	Camp Ellis	Lobsterfisherman T. Buzzell	800 lb.
Sept. 19, 1948	Portland Press Herald	McKinley	Lobsterfishermen Sam & Norris Young	6½ feet 500 lb. to 600 lb.
Aug. 12, 1951	Portland Sunday Telegram	Frenchman Bay	Tunafishermen L. Norton, et al.	7 feet 1,134 lb.

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[1] Newspaper sources had photographs by which the turtle could be identified. [2] Estimated by source of information, unless noted otherwise. [3] Weighed or measured with known accuracy.

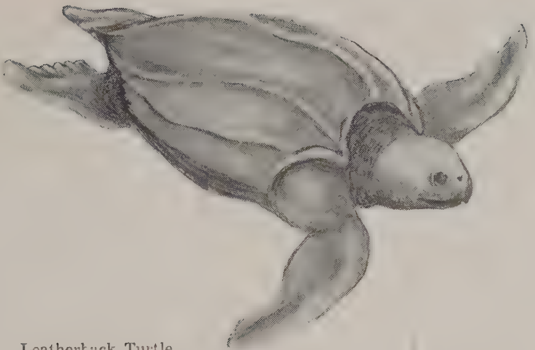

Figure 1. Leatherback Turtle.

probable category, for he (Babcock 1939) has mentioned that some were based on newspaper reports. He felt that such accounts could probably be relied on, and we present them with the feeling that most of them represent leatherback captures, but there is a slight possibility that some might be loggerheads. Leatherbacks have been found in Maine from July to September, most of them during August. There are 23 records showing the finders, and 15 of these were from boats equipped with harpoons to capture swordfish and tuna. Seven leatherbacks were caught by lobstermen or trawl fishermen; in most instances the turtles had become entangled in the lines of the gear. One turtle was found washed ashore.

The loggerhead turtle has a range that extends north to Newfoundland where one was found dead on the Grand Banks (Squires 1954).

The single Maine record is a 32-inch (carapace length) specimen taken in Everett Wallace's floating fish trap at Flag Island, Sagadahoc County, August 15, 1944. Accompanying this turtle was the oceanic crab *Planes minutus*, reported by Chace (1951). Chace had been incorrectly told by Leslie W. Scattergood that New Harbor was the locality of capture. The turtle was kept alive in the Fisheries Research Station aquarium at Boothbay Harbor until October, when it was released in an unused lobster pound in John's Bay. Its remains were found the following spring. During its captivity, it refused to eat a wide variety of seafood offered it.

The range of the ridley turtle extends north to Nova Scotia (Conant 1958). Squires (1954) believed that a "large grey turtle" sighted by a fisherman on the Newfoundland coast was probably a ridley, but this observation cannot be considered as grounds for extending the known range of this species.

The ridley turtle was at one time considered to be less common than the loggerhead, which it somewhat resembles. In his 1919 publication Babcock listed the loggerhead, but not the ridley; in 1930, he reported one early ridley record. In his 1938 report Babcock gave this one record of a ridley in Massachusetts and declared that the loggerhead was the commonest sea turtle in New England. Dodge (1944) examined specimens in Massachusetts museums and found that eight ridleys had been mistakenly identified as loggerheads. There were no loggerhead specimens. Bleakney (1955) found similar mistaken labelling on three ridleys in the Nova Scotia Museum of Science and one in the National Museum of Canada; all had been labelled as loggerheads. The Grand Banks loggerhead is the only authentic Canadian Atlantic record (Squires 1954). It appears that the ridley is much more common than the loggerhead in the Gulf of Maine and northwards.

The only Maine record is a 17-inch (carapace length) specimen caught in Maurice Pye's floating fish trap at Small Point, Sagadahoc County, July 19, 1942. This was exhibited at the Fisheries Research Station aquarium in Boothbay Harbor during the summer. Like the loggerhead, it refused to eat during captivity. In September, it was killed and made into a stew, which was not particularly outstanding.

A stationary type of fishing gear that is effective for small turtles is the floating fish trap. There was a possibility that Maine fish trap operators might catch smaller specimens of turtles and fail to report them to newspapers, fisheries wardens, or the Bureau of Commercial Fisheries Biological Laboratory. If this were the case, turtles might be more common than we realized. Several fishermen who have operated fish traps for three or more decades were interviewed. Ted Farrin, who has two fish traps in Johns Bay, has never caught a turtle. Maurice Pye, who has two fish traps at Small Point, has captured the one ridley. A further source of information is Maine Department of Sea and Shore Fisheries Warden Supervisor Owen Richardson, who has spent most of his life in the center of the fish trap region — Small Point and West Point. Richardson has not heard of any turtles being taken except for the two mentioned above. It seems evident that marine turtles appear in Maine only as casual strays from more southern waters.

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OBSERVATIONS ON THE FECUNDITY OF THE TOMCOD, *MICROGADUS TOMCOD* (Walbaum).—The tomcod, a relatively common inshore fish, is much sought after by Massachusetts fishermen, especially during the winter months. Little is known, however, of the fecundity of this fish and such data are presented here.

A total of 100 tomcod used in this study were collected, using hooks baited with the sea worm, *Nereis virens* Sars, along the coast of Hull, Massachusetts, during three sampling trips in October, November, and December 1959. The sex ratio was approximately one male to every three females (27♂ to 73♀) in the total sample. In the laboratory the gonads from females were removed, weighed to the nearest tenth of a gram and measured in length to the nearest millime-

TABLE 1. AVERAGE NUMBER OF OVA PRODUCED BY TOMCOD, *Microgadus tomcod*

Date	Sample number[1]	Paired ovary number	Weight of paired ovary (grams)	Average weight	Number of ova equal to one gram	Total number of ova	Average number of ova	Length of ovary mass (mm.)	Average length	Length of fish (mm.)	Average length
10/25/59	1	1	3.3		3,506	11,570		35		205	
		2	6.3		2,700	17,010		50		340	
		3	6.2		2,750	17,050		47		180	
		4	2.2		2,579	5,674		23		170	
		5	2.4		5,841	14,018		33		202	
			20.4	4.08	Total	65,322	13,064	188	37.6	1,097	219
11/14/59	2	1	18.7		1,026	19,186		55		215	
		2	14.1		1,392	19,627		55		255	
		3	6.6		2,112	13,939		40		205	
		4	12.6		1,717	21,634		50		220	
		5	10.4		1,734	18,034		50		190	
			62.4	12.48	Total	92,420	18,484	250	50.0	1,085	217
12/12/59	3	1	10.4		488	5,075		100		208	
		2	44.2		560	24,752		70		210	
		3	48.7		610	29,707		75		221	
		4	33.0		590	19,470		75		225	
		5	56.5		560	31,640		85		220	
			192.8	38.56	Total	110,644	22,129	405	81.0	1,084	217
	1 + 2 + 3			18.37			17,892		56.2		
	2 + 3			25.52			20,307		65.5		

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[1] Samples two and three were taken during the periods closest to spawning and represent the closest approximation of actual spawning characteristics.

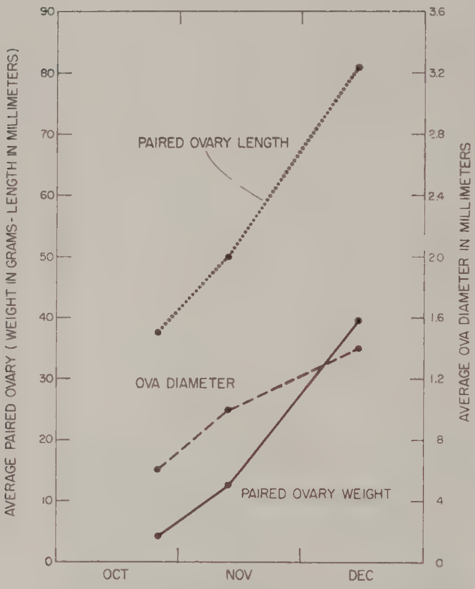

Fig. 1. Averages of ova diameter and paired ovary weight and length of tomcod, *Microgadus tomcod*, collected from October to December 1959.

ter. Examination was made for the presence of parasites, ruptured blood vessels, and general gonad form before preservation in 10 percent formalin solution.

The gonads were stored for a period of two weeks, after which time five pairs of ovaries from each of the three samples were chosen at random for further examination. From each pair, the number of ova in one gram was determined. The total number of ova present in each pair of ovaries was then estimated by multiplying the number of ova in one gram by the total weight of the pair. The average total number for each of the three samples, and the average of these averages, are given in Table 1. The mature tomcod produces an average of 20,000 ova, with a minimum of 6,000 and a maximum of 30,000. The ova showed an average increase in diameter from 0.6 mm. in October to 1.4 mm. in December (Fig. 1). Fig. 1 also shows the increase in ovary weight and length from the early developmental stages in October to December, when the peak of spawning activity is reached. The average weight of the mature paired ovary was 26 grams and the average length was 66 mm. (Table 1).

Bigelow and Schroeder (1953, *Fish. Bull. U. S. Fish and Wild. Serv. 53(74):577*) state that the spawning season of the tomcod begins in November and extends into February, with the peak beginning in late December. Our data are in agreement with their findings. A number of fertilized ova collected from Hull Harbor, December 19, had a conspicuous oil globule and distinguishable eye bulge. The ovaries of fish sampled increased in both length and weight from October to December. This increase seems to result from an increase in individual ova diamter (Fig. 1) and numbers of developing ova (Table 1).

Examination of mature eggs taken from a group of ovaries of the December 12th sample, showed an ova diameter of 1.4 mm. to 1.5 mm. This value agrees with the 1.5 diameter of newly spawned ova reported by Bigelow and Schroeder (*ibid*).

No significant observations were made on the presence of parasites and ruptured blood vessels; only gonad form was found to differ during the three months of sampling. The increase in gonad size seemed to constrict the alimentary canal and other internal organs; however, no critical analysis of this condition was made.—EVERETT SCHANER, *Oceanographic Laboratory, Randolph High School, Randolph, Massachusetts,* KENNETH SHERMAN,[1] *United States Fish and Wildlife Service, Bureau of Commercial Fisheries, Honolulu, Hawaii.*

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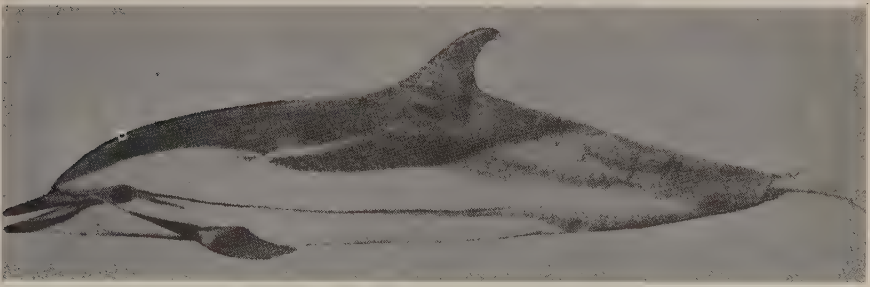
[1] Formerly on the staff as biology instructor at Randolph High School, Randolph, Massachusetts. Published by permission of the Director, U. S. Bureau of Commercial Fisheries.

A DOLPHIN *STENELLA* FROM WASHINGTON STATE

#63



The fresh carcass of a dolphin was found at the door of the State Department of Game, Olympia, Washington, on Monday morning, February 15, 1960. It showed no evidence of injury. Richard Bolding photographed it (fig. 1). James W. Fitzgerald and James Mighell, of the State Department of Fisheries, examined it carefully and concluded, from sand clinging to the body, that it may have come from an ocean beach. In letter of May 13, 1960, Fitzgerald estimated the weight of the dolphin at 350 pounds.

He gave the following description: "Black lateral bands from the eye to the front flipper and from the eye to the anus were very clear. The specimen was a female. It was seven feet eight inches long (234 cm.), measured from snout to center of fluke. The lower jaw had forty-one teeth on each side. A thirteen-pound fetus was removed and later displayed at a local boat show. The stomach was empty except for several hundred small roundworms. The liver, heart, and lungs appeared devoid of parasites. Large cysts were observed in the body cavity. These were three to four centimeters in diameter and were located in the mesentery. They were covered with tough tissue. Small bladderworm-like cysts were observed in the adipose tissue covering the body. These were most numerous posteriorly. About forty were observed while cutting along the backbone. After inspection the carcass was cut up and put into a pond for fish food and fertilizer. The meat appeared to be quite well liked by young chinook salmon."

If this specimen is truly from Washington waters, it represents the third record for the State (*Murrelet*, 1953, 34:28). Two specimens were obtained earlier near Westport.

For bibliographic purposes, the specimen is identified as *Stenella caeruleo-albus* (Meyen) 1833. Many specific names for the form, or forms, of *Stenella* of the North Pacific are now used. The present writer accepts the interpretation of Tomilin (1957, p. 554) that there is only one species in the North Pacific. (A. G. Tomilin. 1957. [Animals of USSR and adjacent lands. Tom 9. Cetacea.] Moscow, Akad. Nauk, SSSR, 756 p., in Russian.)

Appreciation is expressed to the biologists who photographed and measured the specimen, and to J. Burton Lauckhart who first called our attention to it.—VICTOR B. SCHEFFER, *U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Sand Point Naval Air Station, Seattle* 15, *Washington.* 6 July 1960.

Reprint from The Murrelet, May-September, 1960, Volume 41 (2): 23

EXTRAIT DE MAMMALIA Tome 24 N° 3 Septembre 1960

EARLY EMBRYOS OF THE NORTHERN FUR SEAL

by

Victor B. Scheffer

U.S. Fish and Wildlife Service, Seattle

Etude de stades précoces, non encore connus, d'embryons de *Callorhinus ursinus*.

This note calls attention to three specimens of *Callorhinus ursinus* representing hitherto unknown stages of prenatal development between the blastocyst and a fetus of 85 mm. crown-rump length, weight 23.7 g., collected 14 February 1958.

The mean date of impregnation of the fur seal is in mid-July (Bartholomew and Hoel, *J. Mammal.*, 34 : 433 ; 1953). The mean date of implantation is supposed to be 3-4 months later, in early November. This hypothetical date is based on reverse extrapolation of the measured weights of 366 fetuses collected at sea between mid-January and the end of June (D. G. Chapman, *in lit.*, 1957). During the months of June through September each year biologists on the fur seal breeding grounds — the Pribilof Islands of Alaska — have examined many thousands of female genital tracts. In none has an embryo been seen. From a collection of 100 females taken on 27 October 1947, Pearson and Enders (*Anat. Rec.*, 111 : 701 ; 1951) recovered 10 blastocysts, diameter 0.37-2.0 mm. In an attempt to find still larger embryos, biologists examined the genital tracts of three females, 6 years old or older, killed on 28 November 1951. None was visibly pregnant. Again, on 10 December 1957, a search was made for adult females on the breeding grounds, but all had gone to sea on migration. On 18 November 1958, four females, age 7 years old or older, were collected ; none was visibly pregnant. Finally, on 3 December 1958, five adult females, 7 years old or older, were collected on St. Paul Island ; and in each of three a single embryo was found.

The question comes to mind « How can we reconcile (a) the fact that only three embryos were found in 12 adult genital tracts

collected November-December with (b) the hypothesis that implantation is most frequent in early November ? » The suggestion is made that perhaps females which remain belatedly on the breeding grounds into November are atypical and that a higher percentage of implanted individuals would be found among females collected at sea.

Selected information on the three embryos is given in table 1, and a photograph of the best-preserved specimen is reproduced in Plate XVIII. The data in the table show that, for this particular sample, the gestation chamber is 6-19 times larger then the embryo it contains.

The author gratefully acknowledges the help of Roy Hurd and James P. Yeager in collecting the seals ; of Carl E. Abegglen and Gordon C. Pike in dissecting the genital tracts.

Table I

Fur seal embryos in formalin : size of embryo and gestation chamber

Specimen number	Crown-rump length, mm.	A « Diameter » of embryo, mm. (*)	B « Diameter » of chamber, mm. (*)	Ratio B/A	$(B/A)^3$
8	10	7.5	20	2.67	19.0
5	10	8.5	16	1.88	6.6
6	20	17.0	30	1.79	5.7

(*) Diameter of a sphere of estimated equal volume.

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V. B. Scheffer. — Jeunes embryons de *Callorhinus ursinus*.

Résumé

Description de stades embryonnaires encore inconnus de *C. ursinus :* trois embryons de 10, 10 et 20 mm respectivement, collectés aux Pribilof le 3 décembre 1958. L'auteur pense que les femelles qui restent tardivement à terre sont atypiques (3 embryons seulement trouvés en novembre-décembre sur 12 femelles examinées) et qu'en mer à la même date le pourcentage d'implantation doit être beaucoup plus élevé, celle-ci ayant lieu au début de novembre.

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EXTRAIT DE MAMMALIA Tome 24 N° 3 Septembre 1960

WEIGHTS OF ORGANS AND GLANDS IN THÈ NORTHERN FUR SEAL

by

Victor B. Scheffer

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Çe travail réunit de très nombreuses données sur le poids des différents organes de *Callorhinus ursinus*. Ces mesures, poids des organes et pourcentage en poids total des individus, sont de plus comparées aux données connues chez l'homme et le chien.

The weights of certain organs and glands in the fur seal *Callorhinus ursinus* are placed on record here for the benefit of students of mammalian anatomy and physiology. The weights were obtained at odd moments in the course of studies carried on between 1940 and 1959 on the Pribilof Islands, Alaska. The body parts are listed alphabetically. Shown in parentheses for each specimen is the percentage weight, or grams/100 grams body weight. Comparisons are made between percentage weight of the body part in the fur seal and in the dog or man. National Research Council (1956, pp. 162-163, hereafter cited as NRC) gives mean organ weights of two male and two female dogs, and of a large series of men and women.

Adrenals. — One adrenal, bean-shaped, not positively identified, wt. 6.5 g., in 10-year male, 181 kg. (0.0036 %). This value, when doubled for the pair, is not far below the 0.01 % shown for the dog.

Brain. — Wt. 198 g. in newborn male, 4.41 kg. (4.49 %). Wt. 347 g. in 3-year male, about 28 kg. (1.24 %). Wt. 367 g. in 10-year male, 181 kg. (0.20 %). With relation to growth of the body, the growth of the brain lags far behind. The percentage weight of the dog brain (0.59 %) is midway between the percentage weights of 3-year-old and 10-year-old fur seals.

EYES. — Wt. 95 g. and 92 g. in a subadult and an adult male, 85 kg. (0.11 %) and 170 kg. (0.054 %). Wt. 78 g. and 85 g. in two adult females, 34 kg. (0.23 %) and 35 kg. (0.24 %). The percentage weight of the dog eyes (0.10 %) resembles that of the subadult male seal, is twice that of the adult male seal, and is one-half that of the adult female seal. (Weights, in part, from Thomas P. O'Brien, *in lit.*).

HEART. — Wt. 50 g. in full-term female fetus, 4.3 kg. (1.16 %). Wt. 168 g. and 175 g. in two 3-year males, each about 28 kg. (0.60 and 0.63 %). Wt. 770 g. and 660 g. in two adult males, 9 years and 118 kg. (0.41 %), 10 years and 181 kg. (0.36 %). The growth of the heart does not keep pace with the growth of the body. The percent weight (0.85 %) of the dog heart is between that of the fetal and the 3-year-old fur seal.

INTESTINES (See stomach and intestines).

KIDNEYS. — Wt. 45 g. in full-term female fetus, 4.3 kg. (1.05 %). Wt. 198 g. in 3-year male, about 28 kg. (0.71 %). Wt. 680 g. and 480 g. in two adult males, 9 years and 188 kg., 10 years and 181 kg. (0.33 and 0.27 %). The percentage weight of the adult fur-seal kidney resembles that of the dog (0.30 %).

LIVER (with gall bladder). — Wt. 206 g. in newborn male, 4.3 kg. (4.79 %). Wt. 361 g. in full-term female fetus, 4.3 kg. (8.40 %).

Sanford and others (1949, p. 12) gave the liver weight of 157 subadult and young-adult males of various ages, while Scheffer and Wilke (1953, p. 133) gave the mean body weight of 171 males of corresponding ages. The data presented by these authors are combined below :

AGE (years)	N	LIVER Mean weight (grams)	N	BODY Mean weight (kilograms)	LIVER/BODY (percent)
2	29	649	5	20.9	3.11
3	95	980	90	28.0	3.50
4	24	1243	26	35.5	3.50
5	—	—	28	44.9	—
6	9	1997	22	60.7	3,29
Total	157	—	171	—	—

Wt. 7,257 g. and 4,760 g. in two adult males, 9 years and 188 kg., 10 years and 181 kg. (3.86 and 2.63 %). The percentage weight of the adult fur-seal liver resembles that of the dog (2.94 %).

Lungs. — Wt. 62 g. in full-term female fetus, 4.3 kg. (1.44 %). Wt. (including bronchi, trachea, and glottis) 459 g. in 3-year male, about 28 kg. Wt. 1,700 g. (1,950 g. with bronchi and trachea) in 10-year male, 181 kg. (0.94 %). The percentage weight of the adult fur-seal lung is identical with that shown for the dog (0.94 %). One might have expected to find a larger lung in the seal, an animal capable of diving to depths of 40 fathoms and remaining submerged perhaps 15 minutes.

Ovaries. — Ovaries of freshly killed seals were examined on St. Paul Island in summer of 1953 and their weights were recorded by Ford Wilke (MS, 1953). The weights, together with mean body weights (Scheffer and Wilke, *op. cit.*) are combined below.

		OVARIES			BODY	
AGE (years)	N	*Mean weight (grams)* *right*	*left*	N	Mean weight (kilograms)	OVARIES/BODY (percent)
3	22	4.9	5.2	9	21.2	0.024
4	61	6.3	6.5	7	23.2	0.028
5	156	7.1	7.3	3	28.5	0.025
6	115	7.7	7.8	4	29.9	0.026
7	62	8.0	8.1	2	34.3	0.023
8	46	8.1	8.2	3	36.0	0.023
9	43	8.2	8.6	2	40.4	0.021
10	37	8.2	8.4	5	38.9	0.021
10 +	173	8.9	8.9	3	45.4	0.020
Total	715	—	—	38	—	—

Starting with age of puberty (3-4 years), ovarian weight increases about as body weight. The left ovary is two percent heavier than the right. We are unable to find comparable ovarian weights for the dog, although in women 20-30 years old, mean weight 56 kg., the mean ovarian weight is shown by NRC as 10.16 g. (0.018 %).

Pancreas. — Wt. 131 g. in 3-year male, about 28 kg. (0.47 %). No comparable data for the dog. According to NRC the mean wt. is 85 g. in men 16-17 years old, mean wt. 62 kg. (0.137 %).

Pituitary (hypophysis). — Wt. 0.60 g. in 10-year male, 181 kg. (0.00033 %). No comparable data for the dog. According to NRC the mean wt. is 0.625 g. in men 20-30 years old, mean wt. 71 kg. (0.00088 %).

Spleen. — In July and September 1950, the fresh-spleen weight in 114 females of various ages was recorded. The findings, together with mean body weights from Scheffer and Wilke (*op. cit.*) are given below :

Age (years)	N	Spleen Mean weight (grams)	N	Body Mean weight (kilograms)	Spleen/Body (percent)
0	1	13	16	4.8	0.27
2	5	32	8	16.3	0.20
3	9	43	9	21.2	0.20
4	24	51	7	23.2	0.22
5	34	49	3	28.5	0.17
6	24	60	4	29.9	0.20
7	7	47	2	34.3	0.14
8	1	41	3	36.0	0.11
9	1	127	2	40.4	0.31
10	5	72	5	38.9	0.19
10 +	3	98	3	45.4	0.22
Total	114	—	62	—	—

Wt. 363 g. and 170 g. in two adult males, 9 years and 188 kg., 10 years and 181 kg. (0.19 and 0.094 %).

Not shown in the table is an analysis of spleen weight with relation to reproductive condition. In 62 females age 4 years or older, delivered in the summer of collection, the mean weight of spleen is 54 g. In 37 females age 4 years or older, not recently delivered, the mean weight of spleen is 58 g. In other words, the spleen weight in animals recently delivered appears to be about the same as in those which did not carry a fetus within the year.

Generally speaking, the spleen weight increases as the body weight. The maximum spleen weight recorded is 127 g. NRC does not show percentage weight of spleen in the dog, but in the cheetah (0.15 %), jaguar (0.18 %), and leopard (0.22 %). These resemble the percentages found in the fur seal. Mean wt. 204 g. in men 20-30 years old, mean wt. 71 kg. (0.29 %).

STOMACH AND INTESTINES (empty).

Age and sex	*Large intestine* (grams)	*Small intestine* (grams)	*Stomach* (grams)	*Stomach and intestines* (grams)	*Body* (kilograms)
Subadult male (*)	249	1297	876	2422	85
Adult male (*)	317	2391	1368	4076	170
8-year male	—	—	2041	—	184
10-year male	320	1110	1470	2900	181
Adult female (*)	131	1100	531	1762	34
Adult female (*)	132	794	599	1525	35

(*) Individuals weighed on 24 September 1959 by Thomas P. O'Brien.

In the foregoing samples, the percentage weight of the seal stomach varies between 0.80 % and 1.11 % in males ; betwen 1.56 % and 1.71 % in females. The stomach in men 14-20 years old is relatively much smaller, only 0.21 % of body weight. NRC does not show stomach weight in the dog.

The percentage weight of the seal stomach-intestines combination varies between 1.60 % and 3.40 % in males ; between 4.36 % and 5.18 % in females. Comparable percentage in the dog is 4.83 % ; in man, about 2.5 %.

TESTES. — The weight of the testes in known-age seals has previously been published (Scheffer, 1950, p. 388). These weights, together with mean body weights for males (Scheffer and Wilke, *op. cit.*) are given below :

AGE (years)	N	TESTES Mean weight (grams)	N	BODY Mean weight (kilograms)	TESTES/BODY (percent)
0	7	2.6	23	5.4	0.048
1	1	3.2	12	16.8	0.019
2	24	11.7	5	20.9	0.056
3	111	21.9	90	28.0	0.078
4	150	55.6	26	35.5	0.157
5	26	79.0	28	44.9	0.176
6	22	94.2	22	60.7	0.155
7	6	103.6	6	94.5	0.110
8	4	111.2	4	175.5	0.063
Total	351	—	216	—	—

Maximum testes wt. 151 g. in an adult male in May (age ?), 278 kg. (0.054 %). The actual weight of the testes apparently increases through life. It is relatively greatest during early adulthood, centering in fifth year. The percentage weight of the fur-seal testes is considerably greater than that of man. According to NRC the mean weight of testes is 28.3 g. in men 20-30 years old, mean weight 71 kg. (0.040 %).

THYROIDS. — Wt. of left thyroid 0.7 g. in female pup 4-6 weeks of age, 12.2 kg. (0.0057 %, or estimated 0.0114 % for both). Wt. of both thyroids 12 g. in a 9-year male, 188 kg. (0.0064 %). In the dog, the percentage weight (0.02 %) is three times greater than in the adult fur seal ; in 20-30 year man (0.035 %) five times greater.

TONGUE. — Wt. of two tongues together, 96 g., in males about 3 years of age, about 28 kg. each (0.17 %). No comparable data.

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V. B. SCHEFFER. — Poids des organes et des glandes chez *Callorhinus ursinus.*

Résumé

Cet article réunit de très nombreuses données sur le poids des différents organes de *C. ursinus :* poids de chaque organe et pourcentage en poids de l'individu examiné. Les poids et pourcentages sont de plus comparés à ceux connus chez le chien et chez l'homme. Cet ensemble est destiné en premier lieu à ceux qui étudient la physiologie et l'anatomie des Mammifères.

⁂

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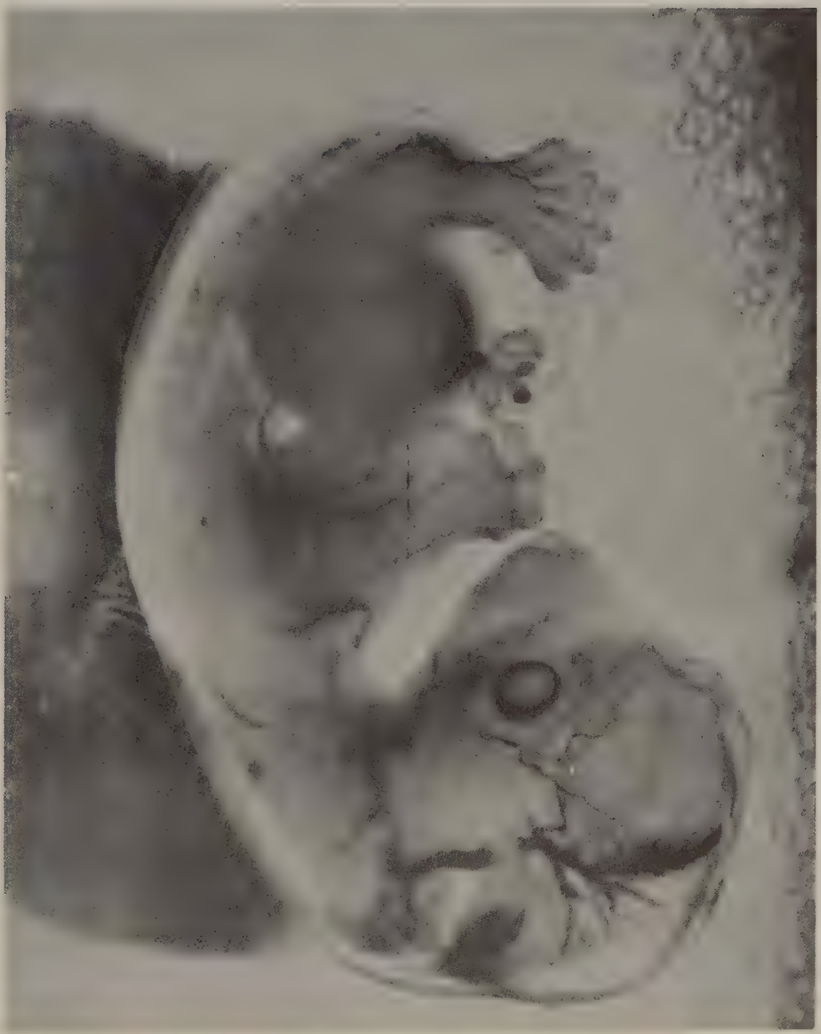

Fur seal embryo, 20 mm. crown-rump length, 3 December 1958, cleared in methyl salicylate. (Photo VBS 4291).

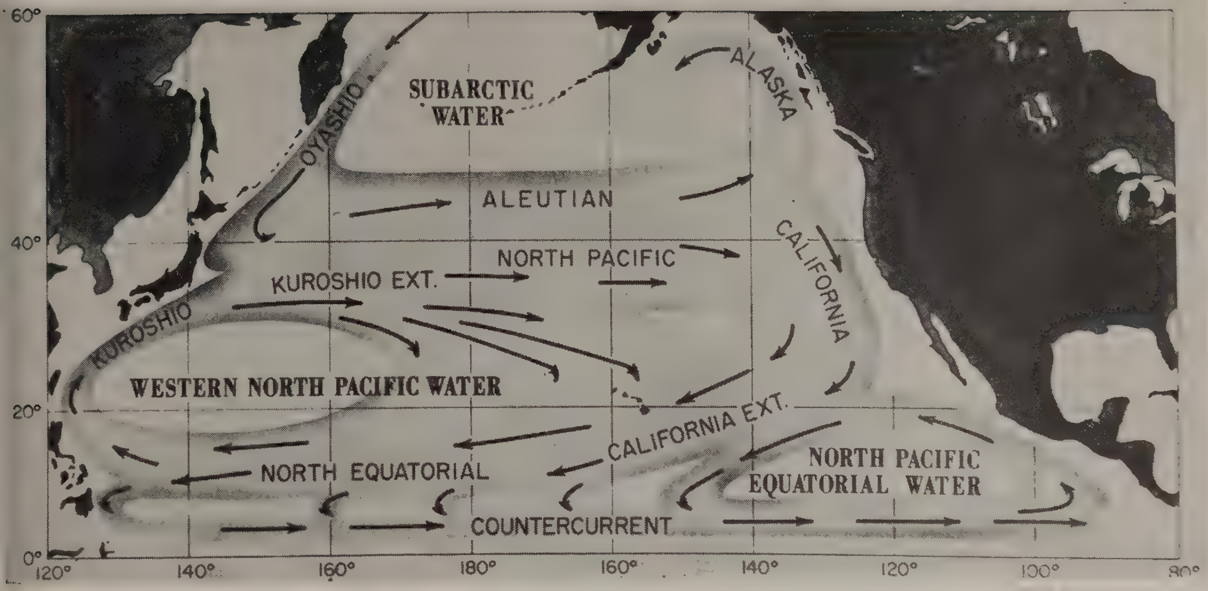

Figure 1.—The major surface current systems in the North Pacific Ocean.

OCEANOGRAPHY and the HAWAIIAN SKIPJACK FISHERY

By
GUNTER H. SECKEL
and
KENNETH D. WALDRON

• In March, 1959, the prediction was made to the tuna industry that the 1959 Hawaiian Skipjack season would be better than average and that the catch might approach the 14 million pounds landed in 1954. Actual 1959 landings of 13 million pounds substantiated the forecast.

This prediction was a by-product of an environmental study in which certain processes in the ocean were discovered to be associated with variations in Skipjack landings. The highlights of the investigation and some of the implications will be discussed below.

Annual Skipjack catches from Hawaiian waters since 1948 have varied between 6 million pounds in 1957 and 14 million pounds in 1954. The landings are seasonal with monthly catches of less than 100,000 pounds during the winter and over 2,500,000 pounds during the summer.

Small Skipjack are present in island waters throughout the year, but the success of the summer season depends upon a high availability of 20-30 pound fish. The fluctuations in landings since 1948 appear to have been due largely to the unexplained variations in availability of these large fish.

The fishery is conducted within a relatively restricted area, which seldom extends beyond 100 miles from land. This contributes to the variations in landings, for low catches in local waters are not balanced by catches from surrounding areas, as is the case in other fisheries. Because the fleet does not range widely, fluctuations in landings are thought to reflect changes in the availability of Skipjack in Hawaiian waters.

The Hawaiian Skipjack fleet has undergone only one recent major change in numbers, and this was a result of two successive poor years, 1957 and 1958. The fleet that fished during 1956 consisted of 28 boats. Only 21 of these fished during 1959, a reduction of 25 percent. During this same period, effort was reduced still further by fishermen leaving the industry. In light of this reduction in effort, the successful 1959 prediction is even more significant.

The seasonal and annual variations in Skipjack landings are a source of economic hardship for both the fishermen and the processors. It is therefore important to investigate the causes, and if possible, predict these fluctuations in advance of the fishing season.

• In the belief that fluctuations in the fishery were associated with changes in the environment, an oceanographic study was initiated. This showed that the Hawaiian Islands are located in the vicinity of a boundary separating two water types, as schematically illustrated in Figure 1. To the north and west is the western North Pacific type, with a salinity of more than 35 parts per thousand (3.5 per cent). To the south and east is the transition type of the California Current Extension, with a salinity of approximately 34.7 parts per thousand (3.47 per cent). It was found that this boundary, which is located just south of the islands during the winter months, begins to move northward early in the year. It passes through the islands in

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NOTE—Mr. Seckel is Oceanographer and Mr. Waldron Fishery Research Biologist on the staff of the Honolulu Biological Laboratory, U. S. Bureau of Commercial Fisheries, Honolulu, Hawaii.

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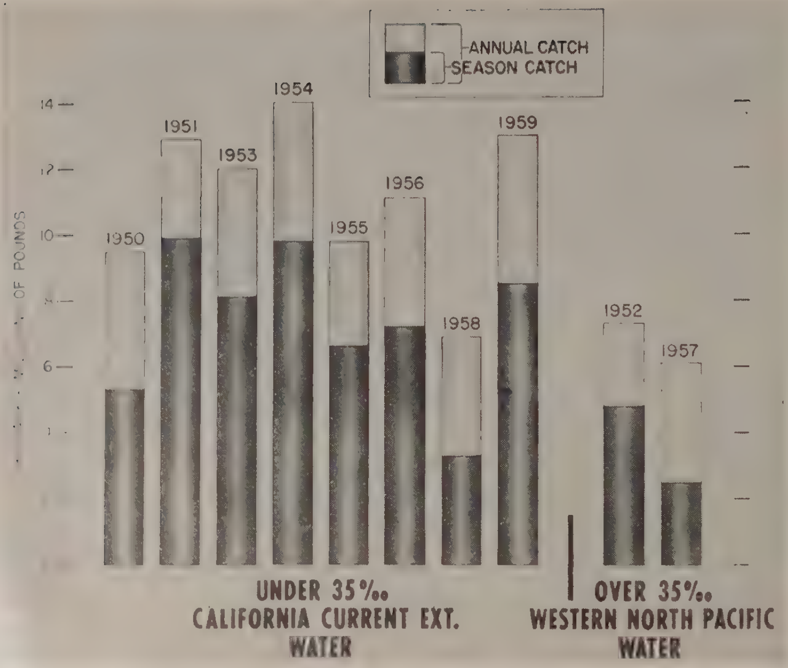

Figure 2.—Hawaiian Skipjack landings as related to the summer salinity of the ocean near Oahu.

April or May and brings the lower salinity water of the California Current Extension. This process is reversed in August, when the boundary begins its southward retreat. It then passes the islands in October or November and brings the high salinity water of the western North Pacific.

The spring movement of the boundary, bringing California Current Extension water into the island area, appears to be associated with the success of the Hawaiian skipjack fishery, as illustrated in Figure 2. Whenever California Current Extension water bathes the islands during the summer, as indicated by salinities of less 35 parts per thousand, the annual Skipjack landings have, with the exception of 1958[1], been average or better than average. Whenever the salinities were higher than 35 parts per thousand, as in 1952 and 1957, the annual landings were less than average.

From these results one can postulate that commercial quantities of Skipjack appear in the islnad area together with the California Current Extension. One can also postulate that there are years in which the California Current System fails to intensify sufficiently to move the boundary into and through the island area. During such years fishing is likely to be poor.

- These ideas about the association between fishing success and oceanography in the Hawaiian Islands as obtained from salinity observations, are also supported by temperature studies. Early and rapid warming of the water near the island of Oahu, as the boundary begins to move northward, appears to be associated with a well developed California Current System. This is usually followed by a decrease in the rate of warming, or even a slight cooling as the boundary passes through the islands. These features were most pronounced in 1954 and 1959, the best postwar fishing years with landings of 14,000,000 and 13,000,000 pounds, respectively.

Of particular interest to the fishing industry is the early warming of the water prior to the fishing season and the fact that this can be monitored by observing surface water temperature. The upper panel of Figure 3 shows that at Koko Head, Oahu, the temperature reaches a minimum during the end of February. It can also be seen that when the water begins to warm the temperature does not rise uniformly. From March to April it rises .4°C., from April to May .3°C., from May to June it rises almost 1°C.

These features become more apparent if one draws the monthly rate of change of temperature as shown in the lower panel of figure 3. Here, when the curve is zero at the end of February, the minimum temperature has been reached and warming begins. This means that the boundary between the western North Pacific and the California Current Extension types of water is beginning to move northward One also notes that the rate of warming decreases from .4°C. at the beginning of April to .3°C. at the beginnin of May. This signals the time whe the boundary moves through the island area. Using sea water temperatures from the Koko Head station therefore, one can detect the beginning of the northward movement o the boundary even though it is located to the south of the islands.

In Figure 4 we see that the time o the northward movement of th boundary is related to the annual Skipjack landings. Whenever this occurre in February, which implies a well developed California Current System, average or better than average fishin years occurred. Northward movemen of the boundary beginning in March which implies a weak California Current System, was associated with low annual landings.

- The results of this investigation indicate that both the seasonal and annual variations in the occurrence o Skipjack within the island region ar indeed associated with environmenta changes. As yet, however, we do no know what environmental factors directly influence Skipjack movements Our lack of knowledge of these factors constitutes an element of uncer

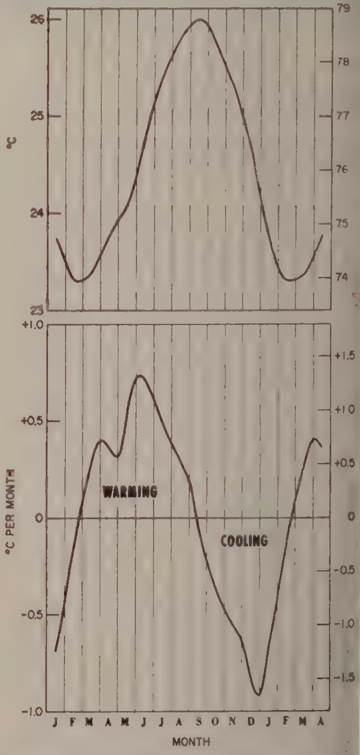

Figure 3.—Average sea water ter peratures at Koko Head, Oahu upper panel. Average monthly ra of change of temperature at Kol Head, Oahu—lower panel.

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[1] In 1958 the minimum summer salinity of 34.9 parts per thousand resembled the western North Pacific water more closely than the 34.7 parts per thousand of the California Current Extension.

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ainty in the prediction. This is knowledge we must have if we are to fully understand the relationship and thus reliably predict the degree of availability of Skipjack in the Hawaiian Islands area during the fishing season.

Several years ago an attempt was made to predict the season (May to August) catch on the basis of the strength of the trade winds earlier in the year. The prediction showed promise, but then failed, probably because the trade winds are only one factor in the circulation of the North Pacific. Similarly, a well or poorly developed California Current System may not always be preceded by the temperature changes noted at Koko Head during the past nine years.

It should be pointed out that the predictive relationship is between changes in the physical environment and landings made later in the year. No consideration is given to changes in the magnitude of the Skipjack stocks on which the Hawaiian fishery is based. The fact that an excellent relationship obtains might indicate that changes in the magnitude of Hawaiian Skipjack stocks from such causes as small year-classes or varying amounts of harvest by the fishermen are not of major importance. If the physical environment is of favorable character, Skipjack should be plentiful in the Hawaiian area. If the environment is unfavorable, few Skipjack of the size usually associated with a good season will appear in the island waters.

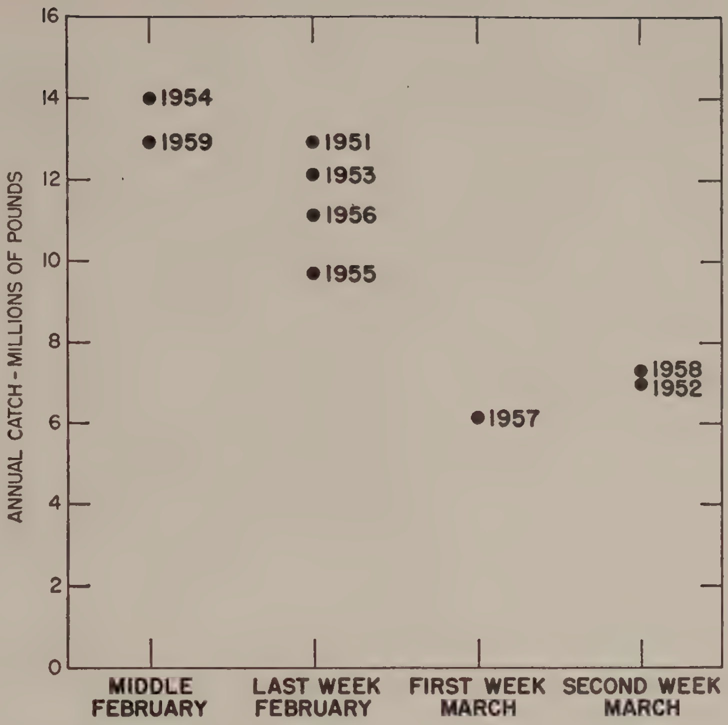

Figure 4.—Hawaiian Skipjack landings as related to the time of spring warming of the ocean at Koko Head, Oahu.

The true value in this investigation does not primarily lie in the discovery of a prediction index but in gaining understanding both of the Skipjack and of the processes in their physical environment. By continuing this approach, we hope to eventually know what factors are responsible for the concentration of Skipjack when the island area is bathed in California Current Extension water.

While the recognition of an apparent association between certain environmental features and the success of the Skipjack fishery was not an entirely unexpected result, it is to be doubted that such a prediction would have been obtained had the investigation been conceived with this as its primary goal. It was designed primarily to help us understand the local oceanographic climate. It may be anticipated that this understanding, when strengthened and extended by future investigations, will find usefulness in other areas, thereby accelerating the fruitful application of science to fisheries on a broad basis.

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ECOLOGICAL STUDIES OF MARINE DERMATITIS PRODUCING SCHISTOSOME LARVAE IN NORTHERN NEW ENGLAND

ECOLOGICAL STUDIES OF MARINE DERMATITIS-PRODUCING SCHISTOSOME LARVAE IN NORTHERN NEW ENGLAND[1]

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Schistosome dermatitis, recognized for over a quarter-century from fresh-water sources (Cort 1928, 1950), was first associated with the marine environment by Penner (1950), and was studied in New England by Stunkard and Hinchliffe (1952) and Sindermann and Gibbs (1953). Cercariae of the avian schistosome *Austrobilharzia variglandis* have been found to be responsible for human dermatitis along the coasts of Long Island, Rhode Island, Massachusetts, and Maine. The mud snail *Nassarius obsoletus* (*Nassa obsoleta*) serves as an intermediate host for the worm in this area, and several species of migratory birds have been implicated as definitive hosts, including the lesser scaup duck (Price 1929), red-breasted merganser (Penner 1953), black duck (Sindermann unpublished data), and probably others. Experimental infections have been obtained in canaries, pigeons, herring gulls, and domestic ducks (Stunkard and Hinchliffe 1952). Human dermatitis is acquired by contact with cercariae in inshore waters near mud snail aggregations, and is an occupational disease of clam diggers (Figure 1).

With the inclusion of the inshore marine environment as a potential cercarial contact area, the factors of salinity and intertidal habitat of the snail host have been added to ecological studies of dermatitis-producing schistosome larvae, and have been found to be important to the maintenance and limitation of the parasite (Sindermann 1956, Sindermann, Rosenfield and Strom 1957).

The present report is a continuation of an attempt to elucidate the relationship of the larval avian schistosome with its snail host in northern New England, and with changes in the physical environment. Particular attention has been directed toward two ecological aspects of public health significance:

(1) seasonal changes in larval schistosome incidence in mud snails, and

(2) the influence of environmental factors on emergence of schistosome cercariae.

Results reported here are based on both field studies and laboratory experiments, the latter conducted in the sea water tanks of the Fisheries Research Station and the Fisheries Biological Laboratory, Boothbay Harbor, Maine.

SEASONAL CHANGES IN INFECTION OF THE SNAIL HOST

This study is concerned with a parasite which alternates between two host populations—snail and bird—which participate in seasonal migrations. Thus it seemed quite probable that seasonal changes of incidence in the snail intermediate would occur, despite the fact that an earlier short-term investigation (Sindermann and Gibbs 1953) had failed to disclose supporting evidence. It is important to note in retrospect that the earlier survey involved snail samples taken from below the mean low tide line. Since later sampling indicated that incidences might vary depending on the location of the snails in relation to high and low tide zones, as well as with season, a 2-year study was made of the infection and the snail host on one tidal mud flat—Back Cove in Portland, Maine. This flat extends for over 1000 yards between mean high and low tide lines. Restriction to one area permitted monthly examination of samples from a series of inshore (high tide zone) and offshore (low tide zone) stations, as well as experimental studies. Examination was limited to snails with a shell length in excess of one centimeter. Whenever possible, a sample consisted of 300 snails, examined microscopically after crushing. Scarcity of snails and icing of flats prevented collection of high tide zone samples from November to April. To insure that the picture which emerged was typical and not peculiar to one mud flat, concurrent but less frequent observations were made on 2 other tidal flats—West Bath and Maquoit Bay. These flats were topographically different from the Portland Back Cove area studied.

Incidence in samples from high and low-tide zone stations on the Portland flat from January 1955 through December 1956 are presented in Figure 2.

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[1] The author wishes to express his thanks for the assistance of Alden Stickney, John Hurst, Aaron Rosenfield, Leroy Strom, Robert Sindermann, and others of the staffs of the Fisheries Research Station and the Fisheries Biological Laboratory, Boothbay Harbor, Me.

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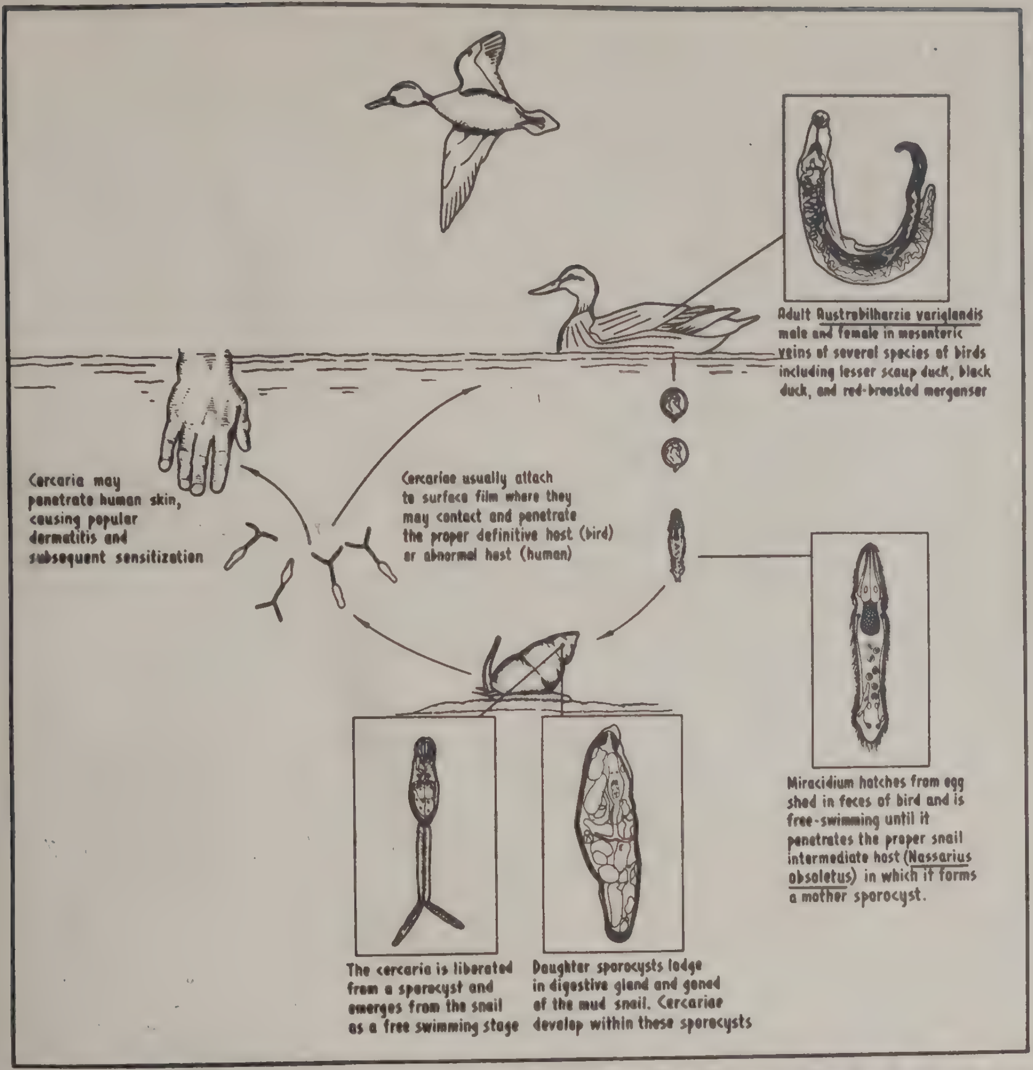

Adult Austrobilharzia variglandis male and female in mesenteric veins of several species of birds including lesser scaup duck, black duck, and red-breasted merganser

Cercaria may penetrate human skin, causing popular dermatitis and subsequent sensitization

Cercariae usually attach to surface film where they may contact and penetrate the proper definitive host (bird) or abnormal host (human)

Miracidium hatches from egg shed in feces of bird and is free-swimming until it penetrates the proper snail intermediate host (Nassarius obsoletus) in which it forms a mother sporocyst.

The cercaria is liberated from a sporocyst and emerges from the snail as a free swimming stage

Daughter sporocysts lodge in digestive gland and gonad of the mud snail. Cercariae develop within these sporocysts

FIG. 1. The life cycle of *Austrobilharzia variglandis* in northern New England. Details of this life cycle were worked out by Stunkard and Hinchliffe (1952) and figures of adult, sporocyst, and cercaria have been redrawn from their paper. The figure of the miracidium has been redrawn from Chu and Cutress (1954).

Examination of these data has indicated that:

(1) larval schistosome infections were significantly more abundant in snails sampled at inshore (high tide zone) stations than at offshore (low tide zone) stations;

(2) incidence in inshore samples increased through the summer and reached a peak in autumn; and

(3) infections at low tide zone stations were consistently low, with only slight increases in April and October.

Investigation of the seasonal migrations of the snail population has also contributed to an understanding of changes in incidence. Seasonal movements of this mollusc in northern New England have not been well-documented, although they have been noted for other areas by Batchelder (1915) and Jenner (1956, 1957). Observations, aided by marking experiments, during the present study indicated that many snails overwintered in dense, quiescent, subsurface aggregates of hundreds to thousands, usually near or below mean low tide line (Figure 3). In April and May these

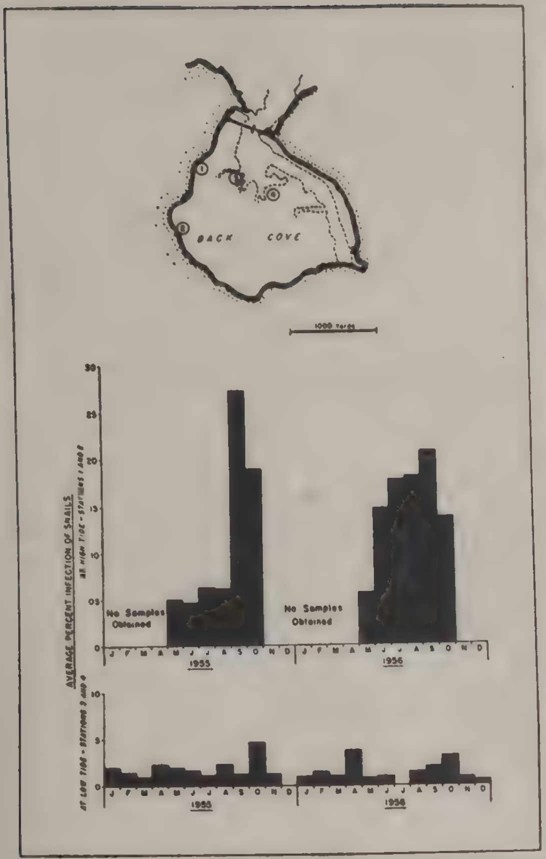

FIG. 2. Back Cove, Portland, Maine, with average monthly incidence of *Austrobilharzia* at high and low tide zone stations.

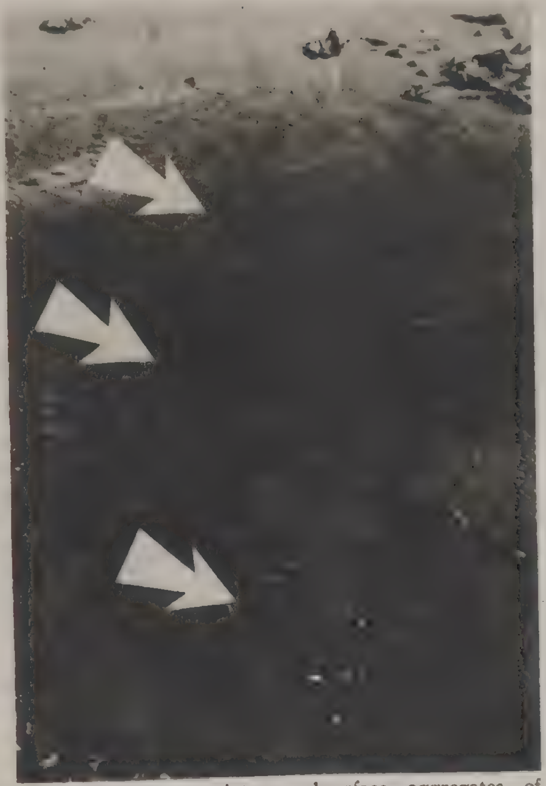

FIG. 3. Three winters subsurface aggregates of *Nassarius obsoletus*. Each is approximately 20 inches in diameter and contains several hundred snails, although larger and smaller aggregates occur.

aggregates began to disperse and many member snails moved over the surface of the flat and up intertidal runoff streams toward the high tide zone, arriving there during late May and remaining throughout the summer. Individuals could be found on the open flat or concentrated about tidal runoff streams in the high tide zone. Egg capsules were produced from June to August. Retreat to the low tide zone begin in September, and by November most snails had again become part of dense quiescent offshore aggregates.

Examination of monthly changes in worm incidence, together with observations of differentially marked infected and unifected snails, indicated that parasitization by *Austrobilharzia variglandis* and certain other larval trematodes (*Zoogonus rubellus* and *Himasthla quissetensis* especially) retarded or inhibited normal offshore movement of the host in autumn—contributing to relatively heavy inshore incidence at this time of year, and leaving the infected snails in the progressively unfavorable environment of the high tide zone in winter. Schistosome infections acquired in autumn began to mature in March, while those acquired in spring began to mature in July. Thus, in late summer and early autumn, snails infected in spring of the current year and in autumn of the previous year contributed to the parasitized segment of the population. This, combined with differential movement of infected and uninfected snails, seemed to provide a basis for a peak of infection in autumn. Pre-existing larval schistosome infections tended to be reduced in winter, in numbers seemingly dependent on the severity of the winter. Mature infections that persisted through the cold months were observed to decrease in vigor by the following July, being characterized by flaccid sporocysts and few cercariae.

Figure 4 summarizes the seasonal sequence of events pertaining to schistosome infections and movements of snails on the study flat.

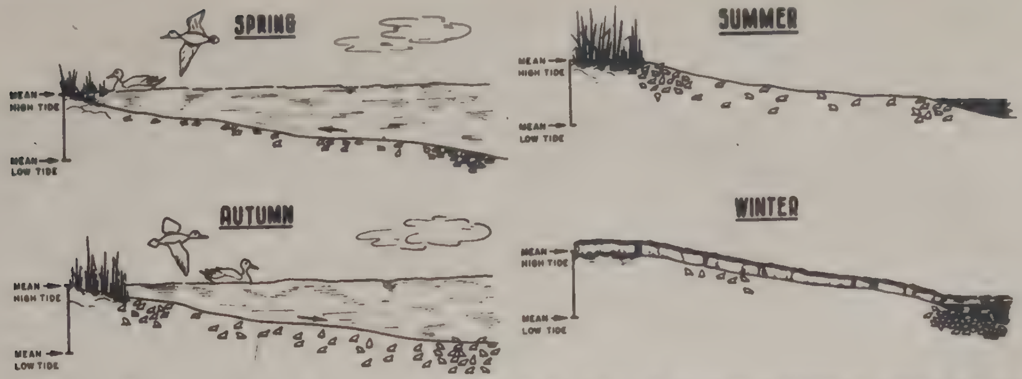

Fig. 4. a. The mud flat in spring. Many *Nassarius* move from low tide zone aggregates toward the high tide zone, while migratory birds congregate in inshore areas, providing a source of infection for snails. Infections which survived from the previous summer begin emitting cercariae when water temperature exceeds 10°C, and infections acquired during the previous autumn mature.

Fig. 4. b. The mud flat in summer. *Nassarius* aggregate in the high tide zone, particularly near intertidal runoff streams, although some snails may be found on the surface of the flat and in the low tide zone. Incidence of larval schistosomes in high tide zone snails rises throughout the summer. Infections acquired in spring mature by midsummer, while infections which survived from the previous summer decline in activity.

Fig. 4. c. The mud flat in autumn. Uninfected *Nassarius* move from the high tide zone over the flat or down intertidal runoff streams toward winter aggregation sites in the low tide zone, but snails with schistosome and other trematode infections tend to remain in the high tide zone. Incidence of larval schistosome infections in inshore areas is highest of the year.

Fig. 4. d. The mud flat in winter. The flat is ice covered intermittently or constantly from December to March, and is scoured during late winter thaws. *Nassarius* are quiescent in dense aggregates of hundreds to thousands below the surface of the mud in the low tide zone, although occasional small clusters of infected snails may be found in mid or high tide zones. Schistosome infections acquired in autumn develop slowly and begin to mature by March.

EXPERIMENTAL STUDIES OF FACTORS INFLUENCING CERCARIAL EMERGENCE

With some knowledge of the seasonal nature and extent of parasitization, it was felt that if the factors controlling release of dermatitis-producing cercariae from infected snails could be determined, it would be possible to assess the potential human danger wherever *Nassarius* were abundant. Considering the intertidal mud-flat habitat of the snail host, certain ecological conditions might limit or enhance cercarial emergence:

(1) salinity—varying with stage of tide, daily, or seasonally;
(2) temperature—varying daily and seasonally;
(3) oxygen tension—varying with stage of tide;
(4) nutrition of the host snail—varying daily or seasonally.

These have been examined experimentally, recognizing that other factors may also prove to be important. Whether changes in the environment of the snail influence cercarial release by acting directly on emerging cercariae or indirectly through the metabolism of the host has not been explored fully, although some indications have been found that changes in host metabolism may influence the rate of cercarial release.

Effect of changes in salinity

Salinity effects on the rate of cercarial emergence were pronounced. Parasitized snails in groups of 25 were kept at 20°C in graded salinities from 5 to 30 $^{0}/oo$, and emergence from each snail recorded daily for 2 months. It was found that greater percentages of parasitized snails emitted cercariae and that the average rate of cercarial emergence was greatest at salinities between 15 and 25 $^{0}/oo$, with reductions above and below these concentrations (Table I).

Table I. Emergence of Cercariae of *Austrobilharsia variglandis* at Various Salinities

Salinity in Parts per Thousand	Percent of Infected Snails Emitting Cercariae	Average Daily Rate of Cercarial Emergence per Snail
5	22	12
10	77	61
15	84	136
20	87	155
25	88	159
30	74	70

It is interesting and perhaps pertinent that, in a later study, curves drawn for oxygen consumption of parasitized *Nassarius* in the same graded salinities essentially paralleled the curves for emergence, with greatest oxygen consumption in the middle salinities and reduction at either end of the salinity gradient (Sindermann and Rosenfield 1957).

Effect of temperature

Low temperatures reduced or inhibited cercarial emergence. Parasitized snails were maintained in the laboratory in running sea water with seasonal light and temperature, and cercarial emergence was checked weekly throughout autumn, winter and spring. Emergence declined in autumn when the water temperature fell below 12°C, and ceased altogether between 6 and 8°, to resume again the following spring when these temperatures were exceeded. Cercarial emergence from snails could be stimulated at any time throughout the winter by placing them in sea water above 10°C.

Effect of environmental oxygen tension

It was observed early in the investigation that when parasitized snails were crowded, or held in specimen jars without frequent changes of sea water, cercarial emergence declined drastically—suggesting that availability of oxygen in the host environment might influence the rate of cercarial emergence. Although measurements of oxygen consumption of parasitized *Nassarius* in decreasing environmental oxygen tensions were not made, artificially increased oxygen tension in water in which infected snails had been crowded resulted in much higher emergence than from control groups without added oxygen.

Effect of host starvation

Parasitized snails were maintained without food in filtered sea water (changed daily) at a constant temperature of 20°C and the emergence from each snail counted daily for 45 days. Within a week from the start of the experiment cercarial emergence assumed a definite periodicity, with peaks every 3 to 4 days, and with little emergence during the intervening time. With few exceptions, the "bursts" of emergence occurred simultaneously in most snails under observation. This experiment was first carried out in the autumn of 1955 and repeated in the summer of 1956, with comparable results. In separate experiments, feeding starved snails after 15 or 30 days resulted in massive cercarial emergence within 48 hours.

DISCUSSION

The avian schistosome *Austrobilharzia variglandis* completes its life cycle in northern New England in a highly mobile situation, involving migratory intermediate and definitive hosts. Parasitization of the snail intermediate has the effect of immobilizing it, at least temporarily, in inshore areas. This increases the opportunity for infection of the definitive host during its autumn migration, but also limits the parasite through death of some of the infected snails thus immobilized in the progressively unfavorable high tide zone.

The seasonal changes in abundance of *Austrobilharzia*, as observed for 2 years, can thus be related to migrations of hosts, extent of infection of hosts, and survival or death of parasitized snails. Higher inshore incidence may be explained by closer proximity of intermediate and definitive hosts. High autumn inshore incidence can result from the simultaneous presence of infections from the previous autumn and the current spring, and from differential movements of normal and parasitized snails. Yearly variations in infection of *Nassarius* have been noted also, but have not been studied in detail. These are probably related to differential survival of parasitized snails through mild or severe winters, and to yearly variations in infection and movements of migrant definitive hosts.

Mere assessment of larval schistosome incidence in snails from any locality does not provide adequate information about the risk of dermatitis unless numbers of emerging cercariae can also be estimated. Environmental variables are known to affect release of trematode cercariae. Cort (1950), in reviewing the status of knowledge of fresh-water schistosome dermatitis, noted that seasons and such physical features of the environment as light and temperature were important in determining risk of dermatitis. Brackett (1940) studied factors influencing emergence of fresh-water schistosome cercariae and found that a rapid increase in temperature increased the rate of emergence. Olivier *et al.* (1953) found that emergence of *Schistosoma mansoni* cercariae from *Australorbis glabratus* was greatly reduced under conditions of anaerobiasis or low environmental oxygen. Kuntz (1947), also working with *S. mansoni*, concluded that temperature was an important factor in cercarial emergence. Rees (1948) studied the effects of light, temperature, and salinity on emergence of the marine larval trematode *Cercaria purpurae* and found that light enhanced emergence,

while any changes from normal salinity were inhibitory.

The investigation reported in this paper has suggested that both salinity and temperature influence emergence of *Austrobilharzia variglandis* cercariae, and that other factors, such as host nutrition and environmental oxygen tension, may also be important. With knowledge of seasonal changes in abundance of infections, and with some understanding of the causes of increased or decreased cercarial emergence under experimental conditions, prediction of risk of marine schistosome dermatitis seems possible.

SUMMARY

Two aspects of the ecology of *Austrobilharzia variglandis*, a marine dermatitis-producing avian schistosome, have been investigated: (1) seasonal changes in infection of the snail intermediate host (*Nassarius obsoletus*) at different levels of an intertidal mud flat, and (2) the influence of environmental factors on rate of cercarial emergence.

Parasite incidence exhibited definite seasonal changes in inshore (high tide zone) snail samples, increasing in summer and reaching a maximum in early autumn. Incidence in samples from the low tide zone remained low (less than 5%) throughout the year, with only slight increases in April and October, and was always lower than in samples from the high tide zone.

Uninfected *Nassarius* migrated between the high and low tide zones, moving inshore in spring and retreating in autumn. Larval schistosome infection retarded or inhibited the autumn offshore migration of the snail host, causing high inshore incidence when migratory birds were most abundant in the area, but also providing a possible mechanism for limiting the infection in the snail population by immobilizing parasitized snails in the unfavorable high tide zone during the winter.

Experimental studies of cercarial emergence demonstrated that maximum emergence occurred in salinities of from 15 to 25 $^{o}/oo$. Temperatures below 12°C reduced cercarial emergence, while those below 6° inhibited emergence completely. Starvation of the host snail resulted in decline in cercarial emergence and the appearance of a 3-4 day period between "bursts" of cercariae, while feeding of starved snails was followed by massive emergence within 48 hours.

When observations on season and location of highest and lowest larval schistosome incidence in mud snails are combined with results of experimental studies of environmental influences on cercarial emergence, it should be possible to determine the risk of human infection wherever *Nassarius* are abundant.

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CARL J. SINDERMANN and DONALD F. MAIRS, U. S. Bureau of Commercial Fisheries. Comparative serology of 5 species of Atlantic clupeoid fishes.

Systematic serological studies of serum proteins began over half a century ago, and have provided information of value to the solution of taxonomic problems. The refinement of quantitative methods permitted determination of serological relationships of species within a genus or family, and results obtained could serve as adjuncts to morphological or paleontological data.

Clupeoid fishes constitute a cosmopolitan group of worldwide economic importance, but the natural relationships of many species are still not completely understood. Among the most abundant species of the family Clupeidae along the east coast of North America are herring, shad, menhaden, alewife, and blueback. This study has attempted to determine their serological relationships, using a combination of turbidimetric and agar diffusion methods. Using the Libby Photronreflectometer to measure precipitin reactions it is possible to calculate relative "serological distances" among several species. With this technique, alewives and bluebacks were found to have a high degree of serological correspondence; shad were found to be closer to the alewife-blueback complex than to either menhaden or herring; while menhaden and herring were found to be remote from all others and from each other, with herring consistently at the greatest serological distance from the other 4 species.

Agar diffusion studies, carried out in multiple system plates, provided support for conclusions drawn from the turbidimetric technique. Although less sensitive for determination of absolute serological distances between species, this method provides another means of visualizing the antigen-antibody reaction. Bands of precipitate are similar in number, position, and intensity when closely related species are tested against a given antiserum; serological dissimilarity is reflected by differences in these same characteristics. In the present study, results from this technique were in agreement with those of the turbidimetric method.

It is planned, with the background of the present study, to compare other morphologically similar but geographically diverse clupeoid species such as *Clupea harengus*, *C. pallasi*, and *C. sprattus*. Comparison of populations or races of widely distributed species such as the herring with serum techniques might also prove instructive.

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FIRST-YEAR GROWTH OF THE WALLEYE, *STIZOSTEDION VITREUM VITREUM* (MITCHILL), AND ASSOCIATED FACTORS IN THE RED LAKES, MINNESOTA

by Lloyd L. Smith, Jr., and Richard L. Pycha

FIRST-YEAR GROWTH OF THE WALLEYE, *STIZOSTEDION VITREUM VITREUM* (MITCHILL), AND ASSOCIATED FACTORS IN THE RED LAKES, MINNESOTA[1]

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ABSTRACT

First-year growth of the walleye, *Stizostedion vitreum vitreum* (Mitchill), was studied from 4,544 fish collected during the first summer of life in the Red Lakes in six seasons and from back calculations on 4,474 fish one year or more in age representing 17 year classes. Sexes did not differ in growth rate. Growth within the season varied greatly in different years and total growth deviated as much as 15.3% from the mean of the entire period. Water temperature, size of brood, and abundance of large walleyes and perch did not affect growth rate. Very early or late spawning influenced total growth during the season and final size and goodness or poorness of a season's growth was determined by the middle of July. Growth rate of young-of-the-year perch and total use of perch as food did not significantly influence growth. Incidence of perch in walleye stomachs ranged from 10.9 to 98.0% and spottail shiner was a more important food item in most years than perch. Total first-year growth of the walleye was apparently determined before fish became a major item in the diet.

INTRODUCTION

The walleye pike, *Stizostedion vitreum vitreum* (Mitchill), is the most important of the eight species taken in the commercial fishery of the Red Lakes, Minnesota. The wide fluctuations in its abundance during the past 25 years have been closely associated with changes in strength of individual year classes. These fluctuations have been associated with changes in the abundance of perch (*Perca flavescens*), and it was suggested by Smith and Krefting (1954) that there may be a dependence of walleyes on the perch for survival of large year classes. Since high commercial production is dependent on strong year classes, the early prediction of brood strength is desirable. If the brood strength could be estimated or the factors producing strong and weak year classes evaluated during the first year of life and 5 to 6 years prior to the entrance of any brood into the catch, many advantages for economic production and possibly for population management would follow. With these facts and possibilities as a background, study of first-year walleyes was started in 1951 and carried through 1957. In addition to the data collected during these years, detailed statistics of abundance, yield, and fishing effort were available from 1930 through 1957 in fishery records. Comprehensive information on spawning seasons in both upper and lower lakes from 1940 to 1957 was secured from hatchery logs. The present study deals primarily with problems of growth and the manner in which it may be affected by various factors in the lake during the first year of life. The bearing of these facts and others on survival and establishment of brood strength will be discussed in a subsequent paper.

Various workers have made substantial contributions to knowledge of first-year life in the walleye. An excellent review of literature up to 1950 is made by Eschmeyer (1950). Maloney and Johnson (1957) discussed various aspects of food and growth in two large Minnesota lakes, and other

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[1] Paper No. 4199, Scientific Journal Series, Minnesota Agricultural Experiment Station, St. Paul 1, Minnesota.

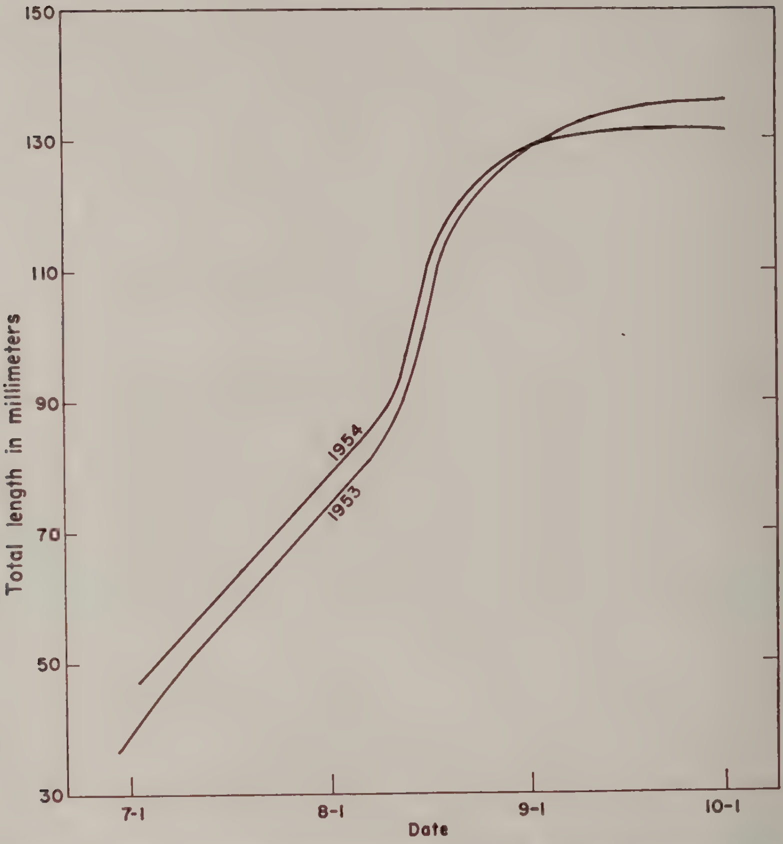

FIG. 1. Growth of young-of-the-year walleye in 1953 and 1954 showing growth compensation in mid-season.

workers have contributed recently to information on first-year growth.

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RATE OF GROWTH

Determination of first-year growth characteristics of the walleye was made from 4,544 fish collected with bag seine and trawl at intervals throughout the summer season from 1951 through 1957. Average total fish lengths at the end of the first growing season in the broods of 1940 through 1956 wer calculated from 4,474 fish one year or mor in age caught with experimental gill net and shore seines. These calculations wer made with a nomograph constructed fro a body-scale length regression based o 1,521 fish ranging from 55.9 to 561.3 m in total length. All young-of-the-year fis and the majority of I-annulus fish used wer preserved in 10% formalin before measure ments were made. Some I-annulus and a older fish were measured in fresh cond tion. Weights of young-of-the-year fis were taken from preserved specimens.

Growth of sexes

In later years of life female walleyes a larger than males of the same age and Esc

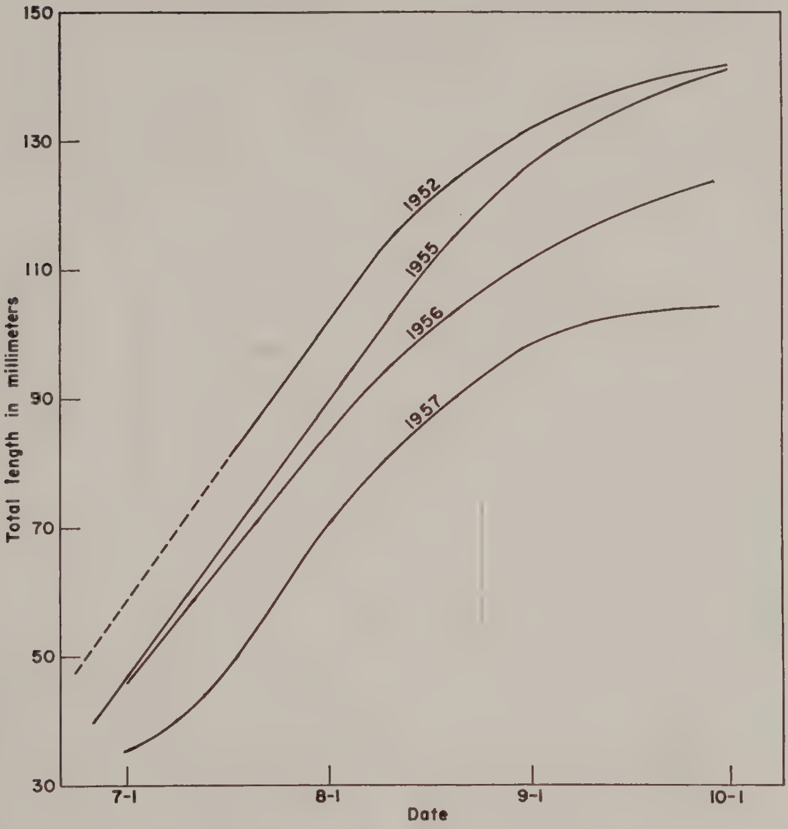

FIG. 2. Growth of young-of-the-year walleye in 1952, 1955, 1956, and 1957.

meyer (1950) shows some indication that this difference also exists during the first year. In 20 samples taken from Red Lakes on different dates throughout the 1955 summer season, there was no significant difference between the mean lengths of males and females from the individual collections. In 10 cases the average length of females was larger, in 6 it was smaller, and in 4 there was less than 1 mm difference. When lengths at I-annulus were compared in 17 year classes from 1940 through 1956, observed differences between sexes were nonsignificant. Samples of first-year fish picked from collections during the summer season of other years similarly showed no differences between sexes. Preliminary scanning of length-frequency data for the two sexes suggested that there might be a skewness in the length distribution of either sex on particular dates that would influence the relative number of larger fish in each group. Distributions were plotted for 5 year classes at first annulus and for several of the large samples during the first growing season. In some instances there appeared to be more large fish among the females, and the distribution was less concentrated about the mean than in the males. These differences were not sufficiently consistent to justify any conclusions. Since significant differences between the sexes could not be shown, all data for the first season's growth were combined for subsequent analyses.

Growth during first season

From 1952 through 1957, 380 samples of

TABLE 1. *Length of walleyes (millimeters) on various dates during first season of growth, 1951–1957*[1] *(numbers in parentheses are percentages of total season's growth)*

Date or item	Year class							Total
	1951	1952	1953	1954	1955	1956	1957[3]	
July 1	—	—	39	—	47	47	36	
			(29)		(33)	(38)	(35)	
July 10	—	—	52	57	60	59	44	
			(39)	(44)	(42)	(48)	(43)	
July 20	80	87	63	68	74	71	55	
	(58)	(58)	(47)	(52)	(52)	(57)	(53)	
July 30	—	100	72	77	87	85	69	
		(66)	(54)	(57)	(61)	(69)	(67)	
August 10	—	115	86	89	103	95	81	
		(77)	(64)	(68)	(73)	(77)	(78)	
August 20	—	124	116	118	115	104	91	
		(83)	(87)	(91)	(81)	(84)	(86)	
August 30	—	131	127	128	125	111	97	
		(87)	(96)	(99)	(88)	(90)	(93)	
I-annulus[2]	140	142	134	130	142	124	—	
Number of young-of-the-year fish	107	280	435	580	526	1,559	1,057	4,544
Number of I-annulus fish	479	59	53	166	246	66	—	1,001
Number of samples	3	8	23	41	73	117	118	383

[1] Taken from smoothed curves of sample means.

[2] Year classes 1952–1956 calculated from I-annulus fish; 1951, from 479 fish of all ages.

[3] Percentages estimated from curve with last point on September 20.

first-year walleyes were taken at intervals during the growing season. In 1951 three samples were taken on July 22–23. The mean lengths of the fish in these collections were plotted and smoothed curves drawn to describe the growth of the different year classes (Figs. 1, 2, Table 1). There was considerable variation in both the rate and pattern of growth in the different seasons. The greatest size differences in mean total length were attained by August 10. On that date in different years there was a maximum spread of 34 mm between 81 mm in 1957 and 115 mm in 1952. By the end of the growing season the range of mean length had decreased to 18 mm between 124 mm in 1956 and 142 mm in 1952. In the 17-year period 1940 to 1956, the average length at the end of the first year of growth was 137 mm with a range of 32 mm between 118 and 150 mm (Table 2).

The rate of growth in most seasons was relatively constant from the latter part of June through the first week in August. After this period in years of moderate or good early growth there was a gradual decline in rate (1951, 1952, 1955, 1956). During years of poor early growth (1953, 1954, 1957) growth rate increased during mid-season and then declined. This acceleration started during the third week of July in 1957 but not until the first week of August in 1953 and 1954. In the latter two years this increased rate extended through August and then tapered off rapidly. It overcame to a substantial degree the effects of slow early growth or late start from delayed hatching. This growth compensation brought final sizes for the season close to the average for the period. In 1957 growth through July 15 was at the slowest rate of the 7 years observed and the moderate compensation left the total length on September 20 far below average.

Since the maximum range in mean length on August 10 in a 7-year period was approximately twice that at the end of the growing season in 15 years and 40% greater than that in two years of a 17-year period, there may be even larger variations between years in mid-season than those noted. The type of growth compensation observed par-

TABLE 2. *Length of walleye in Red Lakes at first annulus and percentage deviation from mean annual increment of I-annulus fish and all other ages in various calendar years, 1940–1956 (1957 estimated)*

Year class	Number of I-annulus fish	Length in mm	Percentage deviation	
			I-annulus fish	Older fish[2]
1940	41	140	+2.0	—
1941	40	135	−1.6	+6.6
1942	12	118	−15.0	−24.8
1943	41	136	−0.9	+22.3
1944	238	142	+3.5	+19.4
1945	148	137	0.0	−19.7
1946	736	141	+2.8	+8.7
1947	748	143	+4.2	+30.7
1948	422	150	+9.0	+25.0
1949	593	146	+6.3	+2.4
1950	386	136	−0.8	−42.2
1951	479	140	+2.0	+3.4
1952[1]	59	142	+3.4	−1.8
1953	53	134	−2.4	−31.9
1954	166	130	−5.4	−4.5
1955	246	142	+3.4	+7.5
1956	66	124	−10.0	−1.4
1957	—	(106)	(−22.0)	—
Mean		137		
Total	4,474			

[1] Calculation of first-year growth 1952–1956 made from I-annulus fish taken in seines; other years from older fish.

[2] Calculation made after Hile (1941) from 5,152 II-annulus and older fish caught in experimental nets and spawning runs 1949–1957.

ticularly in 1953 and 1954 probably occurs in most years when fish are substantially smaller than average size in June and July. First-year growth of fish from Oneida Lake plotted from the data of Raney and Lachner (1942) shows some indication of this compensatory growth.

The percentage of total first-year growth in length which has been completed on any particular date varies considerably in different seasons. By July 20 in all years observed 47 to 58% and in most years more than 50% of the season's increment is completed. At the end of the first 10 days in August, 64 to 78% and, by August 30, 87 to 99% of growth has been made. In years of greatest first-year growth 12 to 13% of the total was added after September 1.

The mean length of Red Lakes walleyes at the end of the first growing season in 17 year classes was 137 mm. This length was somewhat shorter than that reported for Lake of the Woods (Carlander 1945) where fish at I-annulus were 162 mm total length. Hile (1954) found total length at I-annulus in Saginaw Bay to be 162, 170, and 175 mm in different collections. Deason (1933) reports a length of 91 mm standard length and Van Oosten (1948) reported 152 mm total length in Lake Erie. Other authors have found varying growth rates within these ranges from comparable waters.

Annual variations in growth

As has been pointed out above in connection with young-of-the-year, and by numerous authors working with larger fish, there is a marked variation in annual growth increment of walleyes. The growth of walleyes from Red Lakes during the first year of life deviated from the mean growth of all years of the 17-year period, 1940–1956, by as much as 15.3% and the maximum variation between different seasons was 24.0% of the mean annual increment[2] (Table 2). The greatest growth was made in 1948 and the smallest in 1942. When the percentage deviation from the mean annual increment of the I-annulus fish was compared with that of all fish in older age groups in corresponding calendar years from 1941 through 1956, a low correlation ($r = .47$, $p = .073$) was obtained. This coefficient was considerably lower and less significant than that noted by Hile (1954). In some years trends were in opposite directions and in others there was no consistency in degree of change between the groups. It must be concluded that the factors which control the growth of I-annulus fish and older fish are different or do not have equal effect on both groups.

Factors associated with growth

Growth of walleyes during the first year of life is determined by a combination of factors which may include temperature, food availability, time of spawning, abundance of older fish, and abundance of other small competing or forage species.

Temperature—Since temperature is close-

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[2] When estimated total increment of the 1957 season is included, maximum range is approximately 31%.

TABLE 3. *Total length in millimeters of walleyes and perch at the end of the first growing season*

Year class	Length of walleye	Length of perch
1940	140	62
1941	135	65
1942	118	65
1943	136	66
1944	142	64
1945	137	63
1946	141	68
1947	143	61
1948	150	63
1949	146	63
1950	136	54
1951	140	63
1952	142	56
1953	134	75
1954	135	68
1955	142	75
1956	124	68
1957	106[1]	—

[1] Estimated.

ly associated with growth in poikolothermic organisms, its influence on the growth of young walleyes was examined by comparing the summation of air-degree days above 45°F and above 50°F with the total length at the end of the growing season as determined from back calculations on I-annulus and older fish. Comparisons were made with summations for May, June, and July; May, June, July, and August; July and August; August only; August and September; September only; the last two weeks in July, August, and September; for the 17-year period 1940–1956. Use of degree-days calculated from records of the Red Lake weather station was considered valid because the shallow, unstratified lake follows air temperature closely (Smith, *et al.* 1952). While all summations of degree-days tested showed a positive correlation with growth of young walleyes, none were significant below the 15% level. Inclusion of July data made coefficients even lower.

Size of perch—Food studies described below together with similar work by numerous authors indicate that yellow perch is a major food of walleyes and in some cases is the most important item of the diet. Comparison of the growth of young perch in Red Lakes (Pycha and Smith 1955) with the growth of young walleyes in 1952, 1953, 1954, 1955, 1956, and 1957, suggests that slow-growing perch were associated with fast-growing walleyes. The 1952 year class of walleyes ranked second in growth rate during a 17-year period, while the same year class of perch had the slowest growth during the same period. In contrast the 1953 and 1954 broods of walleyes were among the slowest growing broods of the period, while the perch in the same years had a growth substantially above average (Table 3). Correlation between total length of walleyes and the length of perch at the end of the first growing season from 1943 to 1956, however, was non-significant ($r = -.21$, $p = .50$). While this comparison does not lend support to the observations based on recent year classes, the habits and food analyses suggest that the smaller perch would be more readily available to the walleyes over a longer period and therefore might contribute to a faster growth rate. Actual utilization of perch by walleyes was greatest in years when perch were smallest and least when they were large, as shown below in the discussion of food habits.

Abundance of population—Various observations of walleye growth in rearing ponds suggest that growth of young fish in any season is inversely related to the density of the population (Dobie 1956). In Red Lakes an estimate of strength of 15 year classes was made from the examination of approximately 25,000 fish taken from the commercial fishery, experimental gill nets, and shore seines over a 9-year period. Corrections were made for fishing effort and general levels of abundance.[3] The relative strength of the year classes ranged between 5% and 90.9% of the strength of the 1947 brood which was used as a base. Comparison of growth of young fish in different years with the brood strength in the same season showed a superficially positive but nevertheless non-significant relationship. It therefore appears that at population levels existing in Red Lakes the strength of the brood has no demonstrable influence on rate of growth during the first year. Since larger perch and walleyes utilize young perch and other small-fish items taken by fingerling walleyes, competition could be a factor in growth as well as survival. Comparison of abundance levels of commercially available perch and walleye (Smith and Krefting 1954; Smith and Pycha MS) with growth of young walleyes showed no relationship.

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[3] Smith, Lloyd L., Jr., and Richard L. Pycha (MS). Influence of growth and strength of year class of walleye on commercial availability in the Red Lakes, Minnesota.

Date of spawning—From 1941 through 1957, dates of spawning runs and of peak egg production at Waskish hatchery on Upper Red Lake were compared to total growth during the following summer season. Spawning started as early as April 5 and as late as May 2 and continued from 10 to 28 days in various years. Since river water is used in the hatcheries, dates of hatching recorded there are assumed to be approximately the dates when naturally spawned eggs would hatch in the streams. Hatching was completed as early as May 9 and as late as May 29. The influence on growth of the date when river hatching was completed is not clear, perhaps because the growth compensation noted above tends to overcome a late start or because a substantial portion of fish are spawned in the lake where hatching dates are different. Only very early or very late hatching was associated with the size attained by fish at the end of the first growing season. In the two seasons of greatest growth, hatching was over before May 10, while in the two years of poorest growth the hatching was not completed until May 26 and May 29. In the years when detailed growth data through the season are available, the size of the fish in early July appears to be closely related to the time of spawning with the slow years having late hatching and the fast-growing years having early hatching dates. Available information, although inconclusive, suggests that dates of hatching influence size of July fish appreciably but total seasonal growth only when they are very early or very late.

LENGTH-WEIGHT RELATIONSHIP

The length-weight relationship of young walleyes was determined from 1,246 fish which covered a range of 31 to 135 mm in total length, and were collected in the four-year period 1952–1955. The relationship was adequately expressed by the equation

$$W = 0.000007058\ L^{3.03811}$$

where W = weight in grams and L = total length in millimeters.

The relative plumpness of fish has been expressed in various ways for the purpose of comparing different groups of fish (Le-Cren 1951). In the present study the general condition of fish has been expressed as a relative condition factor calculated from the formula

$$K_n = \frac{W}{W_1}$$

where W = weight at capture and W_1 = weight calculated from the length-weight equation.

Since use of relative condition factor (K_n) permits the comparison of fish with reference to plumpness without consideration of factors associated with length, it is useful in detecting differences between fish at different times of year and in different years or between fish of different sizes on the same date. The average relative condition factors for all fish taken each year in the period 1952–1957 varied somewhat (0.992, 1.060, 0.995, 0.948, 0.934, and 0.991 for respective years) but without any consistent relationship to food utilization or rate of growth.

When average value of K_n for successive 15-day periods through the growing season was calculated, there appeared to be a lowering of condition as the season advanced, especially during seasons of slower average growth (Table 4).

Direct observation suggested that the larger fish among those taken on any one date were proportionally heavier than the smaller ones. Therefore, the average conditions (K_n) of all fish larger than the mean length and of those smaller than the mean in each sample were calculated separately.

TABLE 4. *Average relative condition factor (K_n) of young walleye pike above and below average length during various periods of the growing season 1952–1957*

Year and period	Number of fish	Condition factor (K_n) Average	Above mean length	Below mean length
1952				
June 16–30	—	—	—	—
July 1–15	—	—	—	—
July 16–31	49	0.999	0.995	1.007
August 1–15	50	0.935	0.997	0.974
August 16–31	—	—	—	—
1953				
June 16–30	10	1.091	1.115	1.075
July 1–15	113	1.083	1.104	1.057
July 16–31	126	1.076	1.084	1.069
August 1–15	102	1.031	1.049	1.014
August 16–31	53	1.043	1.049	1.035
1954				
June 16–30	—	—	—	—
July 1–15	—	—	—	—
July 16–31	227	1.028	1.056	0.993
August 1–15	67	1.937	0.966	0.908
August 16–31	53	0.982	1.001	0.889
1955				
June 16–30	47	0.929	0.940	0.921
July 1–15	127	0.943	0.950	0.938
July 16–31	158	0.950	0.981	0.923
August 1–15	27	0.943	0.981	0.902
August 16–31	22	0.938	0.892	1.004
1956				
June 16–30	9	1.046	1.015	1.030
July 1–15	615	0.958	0.911	0.941
July 16–31	476	0.914	0.943	0.885
August 1–15	278	0.869	0.914	0.829
August 16–31	163	0.866	0.877	0.854
1957				
June 16–30	—	—	—	—
July 1–15	506	1.045	1.036	1.024
July 16–31	266	0.975	0.972	0.979
August 1–15	150	0.909	0.891	0.932
August 16–31	67	0.931	0.965	0.895

These factors were weighted and combined with those of other samples by 15-day intervals (Table 4). In 24 comparisons between the condition of larger fish and smaller fish, the larger group was heavier in 19 cases. Application of sign test indicates a probability level of 1%. When single large samples were considered separately, the contrast between large and small groups was more marked. The average condition factor (K_n) of fish in separate quartiles of the distribution of individual samples showed a progressive increase from small to larger fish in most cases. In all samples the first quartile was relatively lighter than the fourth.

GROWTH AND FOOD UTILIZATION

During the course of this study the stomachs of 3,652 young-of-the-year walleyes were examined for food selection. The samples were taken in six seasons at four stations on the lake. Of the total number 17.4% were empty and the remainder had a variety of food items among which fish of various species and copepods predominated. The most important food organisms in fish up to 50 mm in length were copepods and to a lesser degree cladocerans.[4] Walleyes larger than 50 mm relied heavily on forage fish and perch but all sizes used copepods and *Leptodora* in some quantities throughout the season.

Since one of the objectives of the study was to ascertain the role of perch in the growth of walleyes, utilization of perch was assessed on the basis of percentage incidence in stomachs of walleyes taking food. Where fish remains could not be identified, they were assigned to various species on the basis of the ratio of the numbers in individual species to the total of identified fish. During the six-year period 1952–1957, perch were present in 10.9 to 98% of the walleyes in different seasons (Table 5). Incidence exceeded 58.5% only in 1952 when sampling was limited. The combined percentage occurrence of other fish species, which included *Notropis hudsonius, N. atherinoides, Catostomus commersonii, Percopsis omiscomaycus, Etheostoma nigrum, Aplodinotus grunniens, Esox lucius,* and *Stizostedion vitreum,* varied from 3.5 to 42.0% in various years. The single most important forage fish item other than perch was *Notropis hudsonius.* In some years (1955, 1956, 1957) the total number of the latter species which was used exceeded the number of perch, in one year (1957) by a margin of 3 to 1. The spottail shiner (*N. hudsonius*) was used most heavily by walleyes smaller

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[4] Smith, Lloyd L., Jr., and John Magnuson (MS). Food of walleyes in Red Lakes, Minnesota.

TABLE 5. *Utilization of perch and other forage fish by young-of-the-year walleye in the Red Lakes expressed as percentage of total fish taking food 1952–1957*

Year	Total fish	Percentage empty	Percentage with perch	Percentage with other fish	Percentage deviation from 18-year growth	Condition factor (K_n)
1952	100	11.0	98.0	3.5	+3.4	0.992
1953	406	23.0	32.5	37.1	−2.4	1.060
1954	400	20.0	58.5	22.1	−5.4	0.995
1955	406	15.2	22.1	28.0	+3.4	0.948
1956	1,423	19.4	46.6	37.3	−10.0	0.934
1957	917	12.5	10.9	42.0	(−22.0)[1]	0.991
Total	3,652					
Average		17.4				

[1] Estimated

than 71 mm in length and during the earlier part of the season.

Perch were important in the diet after walleyes attained a length of 51 mm and the percentage occurrence rose as they increased in size. Even in the larger fish, however, incidence rarely exceeded 50%. When rate of walleye growth was compared to utilization of perch, it was apparent that the two were not strongly related. The two years of greatest growth, 1952 and 1955, had the greatest and next to the smallest incidence of perch (98.0 and 22.1%). The year 1954, which had next to the highest utilization of perch, had next to the lowest growth rate of the 6-year period. In 1957, the year with poorest growth to September 1, incidence of perch was smallest. With the exception of 1952, when sampling was limited to two stations and four samples, the years of heaviest use of all fish as food were the poorest growth years. In 1955, when the incidence of fish in stomachs was lowest of the five years observed, growth rate of walleye was greater than in all except four years of the 18-year period for which growth data are available.

As was pointed out above, total growth for the season appears to be contingent on the size attained by the end of the first week of July, although growth compensation may overcome initial poor starts to some extent. It would appear from the available information that the extent of utilization of fish does not determine the rate of growth or the total growth of the first season.

Food selection and abundance prior to the first 10 days in July would be expected to show more correlation with total first-year growth than later food habits. During that period food of the walleye is made up largely of copepoda, cladocera, and insect larvae. In most years of slower growth there was a higher percentage of empty stomachs, but the average condition factor of all young walleyes was not consistently related to rate of growth (Table 5).

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Colorimetric Determination of Halogenated Nitrophenols Added to Streams as Sea Lamprey Larvicides

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▶ In the application of the specific sea lamprey larvicide, 3-trifluoromethyl-4-nitrophenol (TFM), to certain tributaries of the upper Great Lakes, there is a range of concentration within which all larvae are killed without harm to most other forms of aquatic life. A rapid procedure for determining TFM under field conditions is based on measurement of the intensity of the alkaline color. Variations in the response of the colorimeter caused by changes in stream color are corrected by the use of a nomograph to convert instrumental readings to parts per million of TFM.

A RECENT DISCOVERY of several halogenated nitrophenols which are selectively toxic to sea lampreys (*1*) has resulted in a program of chemical control aimed at eradicating this destructive parasite from the upper Great Lakes. Sea lampreys spend their initial years in larval form in the beds of certain Great Lakes tributaries and at this stage are most vulnerable to attack by selective toxicants (*2*).

The most effective of these toxins to date is 3-trifluoromethyl-4-nitrophenol (TFM, α,α,α - trifluoromethyl - 4 - nitro-*m*-cresol). TFM is utilized in the treatment of streams as a liquid formulation of the more soluble sodium salt of the phenol combined with suitable nontoxic solvents. This compound, like the others of the group, becomes toxic to other forms of aquatic life if its concentration in the water rises above a certain level. The differential toxic effects of TFM vary from stream to stream. In all cases encountered to date, concentrations of 0.5 to 7 p.p.m. of the larvicide in the water have been completely effective.

A colorimetric method has been developed which permits the rapid determination of the larvicide concentration at any point in the treated water mass as it progresses downstream. The method is based upon developing the full, yellow alkaline color of the halogen nitrophenol and analysis of the resulting solution in a colorimeter (*3*). Analytical techniques have been adapted to meet the various problems presented by the particular natural waters in which the nitrophenol is being introduced.

Difficulties due to solid suspended matter have been eliminated by filtering the sample through a Millipore filter and buffering the filtrate at pH 9 with borate. The filtering procedure effectively removes interfering clay suspensions and the borate buffer minimizes the formation of precipitates.

Had the natural color of a stream remained constant during an application of larvicide, this color would have presented no problem. It would have sufficed to adjust the instrument to read zero on the stream water and to construct a standard curve, the standard being made up with the same water. This was the procedure originally employed.

Field experience, however, soon pointed to the need for a procedure for determining the amount of TFM in a given sample when the background color of the water was unknown. This situation arose during treatments at downstream sampling stations when local storms suddenly added unknown amounts of surface water to the stream. The resultant alteration of background color could hardly be determined. Conversely, the subsidence of a stream during a period of treatment was also accompanied by changes in background color. In addition, uncertainties arose below the confluence of two tributaries having differing natural water colors. The color of the water below such a junction changed unpredictably as the volume of flow of the contributing streams varied independently.

Because nitrophenols are practically colorless in acid solution, the color in any acidified sample containing TFM is due to the natural water itself. Although this color is significantly less than the color of the natural water at high pH's, the ratio of these two color intensities is almost constant. This ratio, established as a constant, and an optical measurement of an acidified sample of treated water, together permit calculation of the amount of background color in the buffered sample and adjustment of the colorimeter so that its reading measures the amount of TFM present.

Under conditions of unchanging natural stream color, the concentration of TFM in the treated water could be determined from a standard curve derived from colorimetric measurements of standard solutions of TFM prepared in the untreated water. However, when the background color changed, the form of the standard curve also changed. Hence, a family of standard curves would be required to anticipate changes in background color during treatment. A nomograph was constructed which eliminated the necessity of preparing a series of standard curves and avoided the difficulty of interpolating between them.

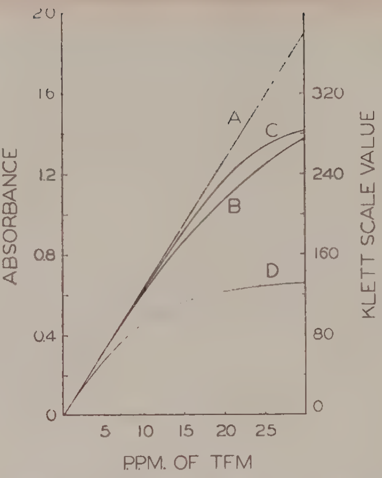

Figure 1. Standard curves for TFM in 1% sodium hydroxide

A. Beckman Model DU spectrophotometer
$\lambda = 395$ mμ
1-cm. Corex cells
Tungsten lamp

B. Klett-Summerson colorimeter
No. 42 filter
1-cm. light path with 1 × 4 cm. cell

C. Bausch & Lomb Spectronic 20 spectrophotometer
$\lambda = 395$ mμ
$^1/_2$-inch cuvette

D. Coleman Model 14 spectrophotometer
$\lambda = 395$ mμ
19-mm. cuvette

INSTRUMENTATION

TFM is a fairly strong acid (pK 6.07 ± 0.03), whose full alkaline color is developed at pH 8.0 and above (*3*). Under these conditions it has a molar absorbance of 13,130 at 395 mμ and in a precise instrument such as a Beckman Model DU spectrophotometer it follows Beer's law (Figure 1, *A*). Because of the broad band of wave lengths (400 to 450 mμ) transmitted by the No. 42 Klett-Summerson filter, however, the absorbance of TFM solutions measured with the Klett-Summerson colorimeter appears to deviate from Beer's law (Figure 1, *B*). The Bausch & Lomb Spectronic 20 spectrophotometer (set at 395 mμ, band width 20 mμ) gives readings corresponding to Beer's law up to about 15 p.p.m. of TFM (Figure 1, *C*). The Coleman Model 14 spectrophotometer (set at 395 mμ, band width 35 mμ) did not yield readings consistent with Beer's law (Figure 1, *D*).

The mechanical complexity and sensitivity of the Beckman Model DU spectrophotometer prohibited field use. The Coleman Model 14 spectrophotometer was rejected for the same reason, as well as the fact that its optical characteristics were unsatisfactory. The Bausch & Lomb Spectronic 20 was also unsatisfactory. Although this instrument has desirable optical characteristics within the range of concentrations normally applied in streams, it does not operate satisfactorily from the portable a.c. power sources available in the field. Operation of the instrument by storage batteries and a Terado converter was also unsatisfactory under field conditions.

The Klett-Summerson colorimeter, in spite of its less desirable optical characteristics, was therefore selected for field use because of its mechanical ruggedness and its satisfactory performance with the power sources available at stream treatment sites.

PROCEDURE

The following colorimetric procedure yields reliable information on the concentration of TFM in a natural water, whether the natural color of the stream is known or not. While the procedure has been developed specifically for TFM, the method should be applicable to any of the other larvicides. The appropriate physical properties of these compounds, as well as those of TFM, have been described in detail (*3*).

Apparatus and Reagents. All measurements are made with a Klett-Summerson photoelectric colorimeter with a No. 42 filter (400 to 450 mμ) and 2 × 4 cm. rectangular cell, utilizing the 4-cm. light path. Values recorded are those read directly from the dial of the instrument. Conventional laboratory ware and medium speed filter paper are used for the removal of coarse particles in samples. A vacuum-operated Millipore Filter (Model XX60, Millipore Filter Corp., Watertown, Mass.) with Type HA Millipore filter paper (pore size 0.45 ± 0.02 micron) is used for the removal of very fine particles. A Beckman portable pH meter has been used successfully in the field, and is indicated for measurements that the analyst at the site of a treatment deems necessary. All pH determinations given in this report were made with a Beckman Zeromatic pH meter.

All chemicals mentioned below are reagent grade unless otherwise specified. 3-Trifluoromethyl-4-nitrophenol (TFM), technical grade, was recrystallized from benzene (m.p. 75–6° C.). Borate buffer, a saturated solution of sodium tetraborate, $Na_2B_4O_7.10H_2O$, in water at

5° C. was prepared from distilled water nd excess salt. Stock solution of TFM 500 p.p.m.) was prepared by dissolving xactly 500 mg. of pure TFM in 10 ml. of 1% NaOH. After the solid is ompletely dissolved, the solution is diluted to 1 liter.

Standard Solutions of TFM. At east two standard solutions containng 1 to 9 p.p.m. of TFM are prepared by diluting appropriate volumes of he 500-p.p.m. stock solution with tream water. This water must have been filtered, first through medium peed filter paper to remove coarse particles, then through the Millipore filter to remove fine suspensions. During the preparation of each standard, sufficient borate buffer is added to ensure a pH of 9.0 ± 0.1. In general, 2 ml. of buffer per liter of solution is sufficient. The Klett scale values of the standards are measured with the colorimeter adjusted to give a zero reading against a filtered stream water blank, buffered with borate. These standards are used to adjust the nomograph as described subsequently.

Determination of Basic-Acidic (B/A) Ratio of Background Color. A sample of about 500 ml. of filtered stream water is divided into two portions. The first is buffered as above, and to the second portion is added 10% hydrochloric acid until the pH is less than 3.0. The Klett scale values of these portions are determined with the colorimeter adjusted to give a zero reading on distilled water. The ratio of the scale reading obtained with the buffered sample to that obtained with the acidic sample is then calculated. This figure is referred to as the B/A ratio.

Calibration of Nomograph. The nomograph consists of three scales (Figure 2). Scale *A* is the Klett scale value of the buffered stream sample containing TFM. Scale *B* refers to the concentration of TFM in this sample in parts per million. Scale *C* represents the Klett scale value of the buffered stream blank which has either been measured directly or calculated from the B/A ratio.

The nomograph is adjusted to a particular stream water before introduction of TFM to the stream. The standard solutions, prepared as described, are used. The Klett scale value of the buffered stream blank is aligned with the known concentrations and scale values of the standards. The Klett scale value and the concentration of one of the standards are located on scales *A* and *B* of the nomograph, respectively. These two points are connected by a straight line which is extended over the movable *C* scale. The *C* scale is then moved along its axis until the known Klett scale value of the buffered stream blank is under this straight line. The Klett scale value of the remaining standard solution is used to check the nomograph setting. The position of the *C* scale is then secured.

Determination of TFM in Water Samples. Stream water samples containing TFM are collected in 500-ml. polyethylene bottles. After preliminary filtration, about 50 ml. (enough to rinse and fill the optical cell) is filtered through the Millipore filter and buffered with 5 to 10 drops of borate solution. When a sample of water is received, the procedure is routine if the background color is known. The Klett scale value is determined with the instrument adjusted to read zero on a solution having the same color as the background.

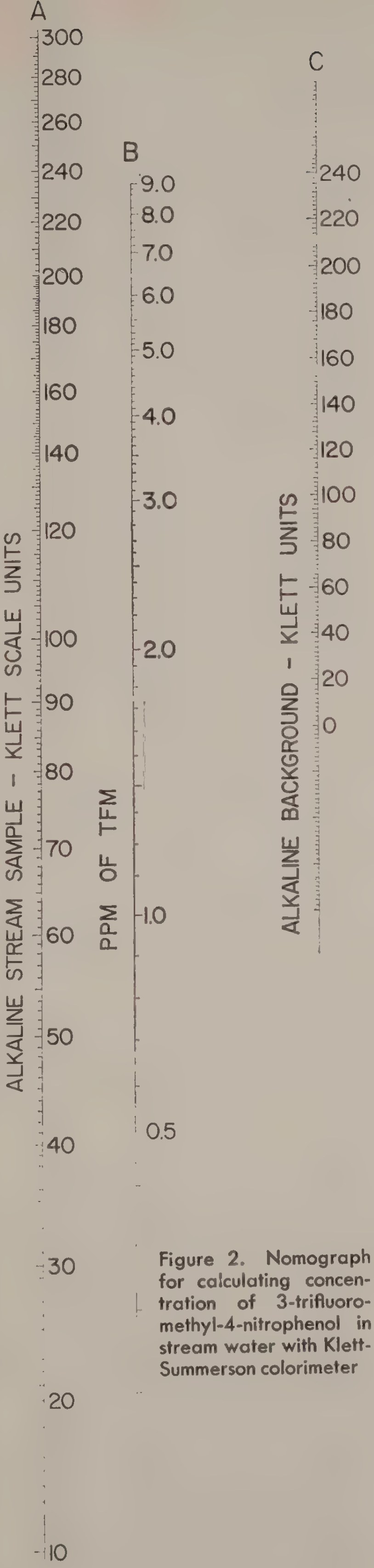

Figure 2. Nomograph for calculating concentration of 3-trifluoromethyl-4-nitrophenol in stream water with Klett-Summerson colorimeter

If the background color is unknown, the filtered sample is divided into two portions, one of which is buffered with borate solution, while the other is acidified to a pH of less than 3.0 with 10% hydrochloric acid. With the colorimeter zeroed on distilled water, the Klett scale value of the acidified sample is determined. This value is multiplied by the B/A ratio; the resulting product represents the Klett scale value of the buffered sample if no TFM were present. The dial of the colorimeter, zeroed on distilled water, is set at this calculated background value and a solution is prepared in the optical cell which zeroes the galvanometer needle with this dial setting. This can be done, if the stream is too dark, by putting a sample of untreated stream water in the cell and adding distilled water, or, if the stream is too light, by employing a darker solution such as sodium chromate. The colorimeter is then adjusted to read zero on this solution. After this adjustment, the Klett scale value of the borate-buffered stream sample containing TFM is determined.

From the known Klett scale values of the buffered stream background color and of a buffered sample containing TFM, the corresponding concentration of TFM can be found by use of the nomograph. To determine the concentration of TFM in a sample of stream water, the Klett scale value of the buffered stream blank is located on scale *C* and the Klett scale value of the buffered stream sample containing TFM is located on scale *A*. A straight line joining these points (in practice either a straight edge or a stretched thread) will intersect the concentration scale (*B*) at a point representing parts per million of TFM present.

EXPERIMENTAL

Prevention of Precipitates in Alkaline Stream Water Samples. Earlier investigations had shown that a pH of at least 8 was necessary to develop the full, alkaline color of the TFM (*3*). Good practice dictated that a pH of about 9 be established in all analytical solutions. However, where pH's above 9 were created in natural waters by the addition of excess alkali, suspensions of insoluble carbonates were likely to form. At first, this was controlled by cautiously adding sodium hydroxide to stream water samples until the pH was between 8.5 and 9.0. This procedure proved impractical in the field, and a buffer was sought which would provide the desired pH level.

A saturated solution of sodium tetraborate was satisfactory; the amount required was always less than 10 ml. per liter and in practice about 2 ml. per liter of treated stream water. The precise quantity to be added must be determined for each stream water, as it will vary with the hardness of the water. The pH of the buffer itself is less than 9.2.

The problem of carbonate precipitates arose also in the preparation of standard solutions of TFM in stream water. Originally, the stock solution of 500 p.p.m. of TFM was also prepared in 1% NaOH. This ensured the conversion of all of the TFM to its more soluble sodium salt (the form of the phenol utilized in actual stream applications) and the development of full nitrophenol color. The pH of standards prepared from this stock solution was usually above 9. This produced turbidity in hard waters. It was not possible to reduce this alkalinity by the addition of borate buffer. These difficulties were not encountered, however, when the stock solution was prepared so that the final sodium hydroxide concentration was only 0.01%. The subsequent addition of buffer to the standards produced a suitable pH, while the same time sufficient caustic was present to convert the TFM to its sodium salt.

The efficacy of this procedure is illustrated by optical measurements of two series of standard solutions which were prepared with water from the Trout River, Presque Isle County, Michigan (Table I). Series A standards were prepared from a 500-p.p.m. stock solution of TFM in 1% NaOH. Series B standards were prepared from a 500-p.p.m. stock solution of TFM in 0.01% NaOH with borate buffer added to each standard at the rate of 2 ml. per liter. The higher Klett scale values observed for the series A standards are due to precipitates produced at the high pH levels resulting from excess caustic in the solutions. Erratic readings in the more highly concentrated solutions of this series are due to differential settling of turbidities formed.

Removal of Clay Suspensions from Stream Samples. Many streams contain suspensions of clay which were not removed by ordinary methods of filtration. The high absorbance of these very fine suspensions remaining in the filtrates reduced instrumental accuracy, while their tendency to settle out at different rates caused variations in background color determinations.

When stream waters containing clay suspensions were passed through Millipore filter paper, rated to remove particles down to 0.45 micron, practically all turbidity was removed. The data in Table II illustrate how Millipore filtration removed suspended matter from waters of the Firesteel River, Ontonagon County, Michigan, and the Stokely River, Ontario. The Firesteel River is a heavily silted stream, whereas the Stokely River appears visually "clear." Turbidity measurements were made with a Hellige Turbidometer, No. 6035, calibrated for the range between 0.5 and 1 p.p.m. of silica as well as higher concentrations.

Both turbidity and absorbance measurements of the filtrates clearly demonstrate the efficiency of the technique. The residual Klett scale values for the Millipore-filtered samples represent only the natural color of the stream water. Many seemingly clear streams, such as the Stokely River, apparently contain enough subvisible suspended matter to affect any measurements made with the Klett-Summerson colorimeter.

Determination of Background Color in the Presence of TFM. A procedure has been described for determining the natural color of a stream when it contains TFM. The validity of this procedure is based on two premises: that the entire Klett scale value for the sample after acidification is due to natural coloring matter in the water, and that for the TFM-free stream water, the ratio (B/A ratio)

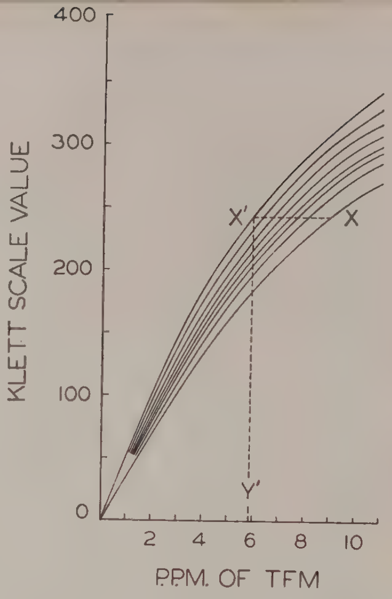

Figure 3. Standard curves for TFM in distilled water and in mixtures of distilled and Milligan Creek water

Uppermost standard curve. TFM in distilled water. Moving downward, successive curves represent TFM in mixtures of Milligan Creek water and 90, 80, 70, 60, 50, 30, and 10% of distilled water

Table I. Klett-Summerson Scale Readings of Standard Solutions of TFM

[Prepared with Trout River water from 500-p.p.m. stock solutions of TFM in (Series A) 1% NaOH and (Series B) in 0.01% NaOH with borate buffer added]

Concn. of TFM, P.P.M.	Series A pH	Series A Klett scale value	Series B pH	Series B Klett scale value
3	9.5	272	8.95	133
5	9.9	390	8.95	193
7	10.4	430	8.95	246
9	10.7	530	8.95	285
11	11.0	495	8.95	320
13	11.2	540	8.95	350

Table II. Removal of Suspended Matter from Firesteel and Stokely River Waters

Treatment	Tube, mm.	Turbidity Measurements: Filter	Reading	P.p.m. as SiO_2	Klett Scale Value
Firesteel River water					
Unfiltered	20	None	32	150	478
1st ordinary filtration	20	None	11.5	12.0	102
2nd ordinary filtration	50	Light	33.5	9.8	92
Millipore filtration	50	Dark	17	0.47	64.5
Stokely River water					
Unfiltered	20	None	25	44.5	56
1st ordinary filtration	50	Light	39	12.5	41
Millipore filtration	50	Dark	12	0.18	14

Table III. Residual Acid Color of TFM Solutions

Concn. of TFM, P.P.M.	Before Acidification pH	Before Acidification Klett scale value	After Acidification pH	After Acidification Klett scale value
A. Solutions prepared from 500-p.p.m. stock solution in 0.01% NaOH and distilled water				
1	6.10	28	2.85	0
5	6.30	162	2.70	3
10	6.90	301	2.85	5
B. Solutions prepared from liquid formulation of TFM and distilled water				
1	4.90	7	2.75	0
5	5.00	41	2.80	4
10	5.20	108	2.70	7

$$\frac{\text{Klett scale value at pH 9}}{\text{Klett scale value at pH 3}}$$

is a constant.

The first premise is reasonable, since the yellow color of nitrophenols is largely discharged by acidification. This was true for TFM standards prepared as described earlier (no buffer added) as well as for aqueous solutions of TFM prepared from one of the commercial liquid formulations currently used in field applications (Table III).

The second premise, that the B/A ratio is a constant, has been demonstrated in several ways. In one experiment, samples of water from Milligan Creek, Presque Isle County, Michigan, were diluted with distilled water and the B/A ratio was derived for each dilution by determining the Klett scale value of acidified and borate-buffered portions. Dilution of a highly colored stream water with a clear dilutant did not affect the B/A ratios; these ratios of diluted samples differed neither from each other nor from that of an undiluted sample of the water in significant degree (Table IV).

In another experiment, waters from streams in the same area having similar B/A ratios but differing color intensities were mixed. Water from Milligan Creek (B/A ratio 1.35) was added to Carp Creek water (B/A ratio 1.36), so that several stages of color intensification of the latter were achieved. The B/A ratios of these mixtures were almost identical with those ratios of the original stream waters (Table V).

The reliability of the assumption that neither dilution nor intensification of the natural color of streams would significantly alter the B/A ratio was further demonstrated under natural conditions by noting changes in this property in periodic water samples taken from a single stream. Water from Carp Creek was collected and examined twice weekly between June 8 and October 15, 1959. In this period, the B/A ratio of the stream water samples had a mean value of 1.37, a range from 1.29 to 1.45, and a standard deviation of ±0.035.

Significant changes in the B/A ratio during the whole period were gradual and tended to reflect broad seasonal variations in precipitation and water level. Short-term fluctuations—i.e., during monthly periods—were, however, so small as to lack significance. Because the duration of a single stream treatment seldom exceeds several days, long-term changes in the B/A ratio are of no practical concern.

A number of streams covering a broad area also were examined to determine the extent of geographic variation of the B/A ratio. Single samples were collected from nine tributaries of eastern Lake Superior and seven tributaries of northern Lake Huron. Lake Superior tributaries were: Big Carp, Cranberry, Goulais, Stokely, Harmony, Chipewa, Batchewana, Sable, and Pancake Rivers, District of Algoma, Ontario. Lake Huron tributaries were: Trout, Schwartz, Carp, and Milligan Creeks and the Ocqueoc River, Presque Isle County, Michigan; and Green and Little Billies Creeks, Cheboygan County, Michigan.

The B/A ratios of waters collected from these streams had a mean value of 1.37, a range from 1.30 to 1.46, and a standard deviation of ± 0.045. The range of values observed for these widely scattered tributaries corresponded very closely to that range recorded for periodic samples from a single stream of the group during a 4-month period. This ratio, therefore, shows little variation from watershed to watershed within rather broad geographic areas in the Great Lakes basin.

Table IV. Effect of Dilution on B/A Ratio for Milligan Creek Water

Sample	pH			Klett Scale Value			B/A Ratio
	Initial	Acidic	Basic	Initial	Acidic	Basic	
Undiluted Milligan creek water	7.70	2.90	8.95	242	190	257	1.35
Diluted with distilled water							
20%	7.65	2.85	8.95	199	156	210	1.34
40%	7.60	2.80	8.95	150	119	162	1.36
75%	7.30	2.90	8.95	66	54	73	1.35

Table V. Effect on B/A Ratio for Carp Creek Water of Intensification of Color by Addition of Milligan Creek Water

(Carp Creek water, B/A ratio 1.36; Milligan Creek water, B/A ratio 1.35)

% Milligan Creek Water in Carp Creek Water	pH			Klett Scale Value			B/A Ratio
	Initial	Acidic	Basic	Initial	Acidic	Basic	
0	8.10	2.95	8.95	82	63	86	1.36
10	8.10	2.80	8.95	100	77	105	1.36
20	8.10	2.95	8.95	116	89	120	1.35
30	8.10	2.75	8.95	131	101	138	1.37
40	8.05	2.70	8.95	150	115	155	1.35
50	8.05	2.90	8.95	165	127	171	1.35

The Nomograph. During exploration of the characteristics of the B/A ratio, several series of unknown concentrations of TFM were prepared in various dilutions of stream waters. When the Klett-Summerson colorimeter had been adjusted to read zero on the appropriate blank, the concentration of TFM in these unknowns was determined by converting the Klett scale value to parts per million from a single calibration curve. However, a change in the natural stream color not only invalidated the calibration of the colorimeter, but also altered the curvature of the standard curve (Klett scale value *vs.* concentration), even when the colorimeter had been readjusted to read zero on a sample of water having the new background color. This latter effect, due probably to the optical characteristics of the instrument, is illustrated in Figure 3, which shows a series of curves derived from standard solutions of TFM in various mixtures of distilled and Milligan Creek water. All standard solutions were prepared in Millipore-filtered and borate-buffered dilutions of creek water, and the colorimeter was adjusted to read zero on the appropriate mixture from which the standards were prepared. The greater the color intensity of the blank, the lower the slope of the curve, so that the Klett scale values for a given concentration of TFM decrease with increasing blank values.

Furthermore, a standard curve prepared with the water of one stream may have a curvature different from that of a curve prepared with water from another stream having an identical background color. It cannot be assumed, then, that water samples from any two streams containing equal concentrations of TFM will yield the same Klett scale values. Thus, to anticipate not only possible changes in background but also unique background characteristics, it would be necessary to provide a family of standard curves for every stream, prepared from a number of dilutions of the natural water. These data would not only be tedious to prepare in the field but difficult to use because of the necessity of interpolating between curves.

The foregoing considerations illustrate that a third variable—viz., stream background value—must be introduced into the determination of TFM concentration. By replacing the customary graphical representation of the standard curve with a nomograph, the analytical technique was made more versatile without sacrificing simplicity. To minimize the effect of instrumental variation and to make possible interpolation between observational data, the nomograph shown in Figure 2 was evolved; it was based on values obtained from the family of curves represented in Figure 3.

The nomograph was constructed in the following manner.

Three parallel straight lines were drawn, representing in order from left to right, (*A*) the Klett scale value for the buffered stream sample containing TFM, (*B*) the concentration of TFM in parts per million, and (*C*) the Klett scale value for the buffered, TFM-free stream water.

The axis, *C*, representing Klett scale values of the borate-buffered stream blanks, was marked off in arithmetic intervals. A point on the sample scale, *A*, was chosen somewhat arbitrarily and assigned a value representing the Klett scale reading of the 9-p.p.m. solution of TFM in distilled water. The zero point of the background scale, *C*, represented the Klett scale value of distilled water. A line was drawn joining these two points which intersected the concentration, *B*, at a point corresponding to 9 p.p.m. This latter point was so designated. The seven Klett scale background values corresponding to the seven mixtures of creek and distilled water next were located as points on the background scale, *C*. Straight lines were drawn from each of these seven points through the 9 p.p.m. point on the *B* scale, making seven more intersections on the sample scale, *A*. The eight points on the *A* scale were then assigned appropriate Klett scale values for the eight 9-p.p.m. standards which were obtained from the corresponding standard curves (Figure 3).

The process was then reversed. The Klett scale value of the 9-p.p.m. standard in the darkest water was equal to that of a reading for a lower concentration of TFM in distilled water (see $X - X'$, Figure 3). A line was drawn on the nomograph joining the zero point of the *C* scale to the lowermost of the points on the *A* scale (Klett scale value of the 9-p.p.m. standard in the darkest water). The intersection of this line with the concentration scale, *B*, corresponded to the concentration of a hypothetical solution of TFM in distilled water. This concentration was determined from the standard curve for distilled water (see $X' - Y'$ in Figure 3) and was so designated on the *B* scale. This point on the *B* scale in turn gave rise to eight more points on the sample scale, *A*. This was accomplished by connecting the points on the *C* scale used previously with the new value located on the concentration scale, *B*, and extending these lines to intersect the sample scale, *A*. This process was repeated, the concentration scale was extended downward, and for each interval of concentration a segment of the *A* scale was constructed. Thus, both of the unknown scales were extended until suitable ranges of concentrations and Klett scale values were obtained.

This process resulted in irregular gaps in scales *A* and *B*. These were filled in by constructing smooth curves relating linear distance on the scale with scale interval. By interpolating from these curves, desirable scale intervals were laid off.

In practice, the *C* scale is movable, so that the nomograph may be adapted to different waters. To set the nomograph for a particular stream, a standard solution of TFM is prepared in the water to be treated, and calibration is carried out as described under "Procedures."

Determination of TFM in Unknown Samples. An experiment was conducted to test the accuracy of the entire procedure for the determination of TFM in stream water samples having unknown background values. These tests simulated conditions which could normally arise during a field application of the larvicide.

Samples of water were obtained from Carp and Milligan Creeks, Presque Isle County, Michigan, and the Stokely and Kaministikwia Rivers, Ontario. A portion of each sample was diluted with an equal volume of distilled water, and, using these mixtures, standard solutions of TFM were prepared. For each hypothetical stream treatment, this diluted stream water represented the conditions prevailing at the start of the application and was used in each instance to determine the B/A ratio and adjust the colorimeter. The standards were used to set the nomograph, as described earlier.

Three unknown solutions of TFM were made up for each stream. One of these unknowns utilized stream water diluted with an equal volume of distilled water, a second was made up with undiluted stream water, and the third was prepared with stream water diluted with twice its volume of distilled water. Thus one unknown was in darker water, one in lighter water, and one in water of the same color intensity as that used for the standards.

Each of the unknowns was treated in the same way. Using B/A ratios previously determined, the buffered background values of the unknowns were calculated and the Klett scale values were determined. The nomograph, appropriately adjusted for each stream, was then used to convert these values to parts per million of TFM in the unknowns.

Table VI. Determination of Unknown Concentrations of TFM in Water from Four Streams

	Background Color			Sample Values			
	Klett Scale Value			Klett Scale Value		TFM, P.P.M.	
Stream	Acid	Basic	B/A ratio	Basic (calcd. blank)	Sample	Calcd.	Actual
Carp Creek							
Undiluted	..	..	...	97	`95	2.2	2.3
Diluted 1:1	35	49	1.40	51	204	5.4	5.5
Diluted 1:2	..	..	...	38	150	3.5	3.6
Milligan Creek							
Undiluted	..	..	...	142	170	5.2	5.3
Diluted 1:1	55	74	1.34	75	173	4.8	4.7
Diluted 1:2	..	..	...	50	115	2.7	2.6
Stokely River							
Undiluted	..	..	...	76	156	4.0	4.1
Diluted 1:1	29	39	1.34	39	110	2.5	2.5
Diluted 1:2	..	..	...	29	220	6.1	6.2
Kaministikwia River							
Undiluted	..	..	...	85	98	2.3	2.2
Diluted 1:1	31	43	1.38	41	153	3.7	3.8
Diluted 1:2	..	..	...	32	208	5.5	5.7

Determinations of concentrations o TFM in these unknowns were neve more than 0.2 p.p.m. at variance wit the actual values. The average erro for 12 determinations was 0.1 (Tabl VI).

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Great Lakes Research

STANFORD H. SMITH

U. S. Bureau of Commercial Fisheries

The federal government has two vessels especially designed for fishery and limnological research on the Great Lakes. Both operated in Lake Superior in 1959.

The large size of the Great Lakes has been a formidable deterrent to intensive and continuous research on their populations of fish, and on the biological characteristics of the lakes themselves. Vessels and equipment required to conduct this work are so expensive to build and so costly to operate that they are seldom obtainable by research organizations. The first large vessels used in fishery and limnological research, the 85-foot *Shearwater* on Lake Erie in 1928–1929, and the 102-foot *Fulmar* on Lake Michigan in 1930–1932, although owned by a single agency (U. S. Bureau of Fisheries), had to depend for support on a number of cooperating agencies.

KNOWLEDGE of the biology of the Great Lakes up to the past decade has been obtained mostly from examining the catches of commercial fishermen or by limited forays of scientists onto the lakes in borrowed or rented vessels. The catch of commercial fishing gear has failed to reveal the true composition of the fish stocks inhabiting the area in which the gear was fished. They have provided little knowledge of other species that live on the fishing grounds, and environmental conditions at the location were totally unknown. In 1953, a new species of dwarf whitefish was discovered in Lake Superior where it had escaped notice only because it was too small to be taken in commercial fishing gear. Biologists in borrowed or rented vessels could not collect the information needed to reveal the complex interrelations among the various species of fish and their environment.

Knowledge gained from examination of the commercial catch and from limited studies with vessels has only served to emphasize the complexity of fishery problems of the Great Lakes. Little has been learned about the factors which influence the distribution and abundance of the various species because information was lacking on their biological requirements. Intensively selective commercial and sport fisheries and the appearance of exotic species (smelt, alewife, and sea lamprey) have made increasingly critical the need to know how all species live together and how they influence each other. Such knowledge as we have of changes in the environment is sufficient only to emphasize the necessity for a better understanding of the physical, chemical, and biological characteristics of the lakes.

In recognition of these needs the states of Ohio, Pennsylvania, province of Ontario, and the U. S. Bureau of Commercial Fisheries have built Great Lakes research vessels during the past decade and the state of Minnesota, Fisheries Research Board of Canada, and various research groups have increased their use of existing special or modified craft for Great Lakes research.

IN 1950, the U. S. Fish and Wildlife Service, Great Lakes Fishery Investigations, constructed the first vessel specially built and equipped to carry on fishery and limnological research on the Great Lakes. This vessel was completed in June 1951 and was christened the M/V *Cisco*. In 1952, the Bureau purchased the gill-net tug *Iva Mae*, which was renamed the M/V *Siscowet*. The boat was completely redesigned and rebuilt in the fall and winter of 1957–58. Only the hull of the original craft was retained. Both of

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pp. 18, 19, 22 + 23

these vessels were finished at Sturgeon Bay, Wisconsin.

The *Cisco* is 60.5 feet long, has a 17.8-foot beam, and 7.5-foot draft; she is powered by a 170-H.P. engine. Equipment includes a 20-KW, AC main generator with a 3-KW, AC auxiliary power supply. The *Cisco* has accommodations for nine people.

The *Siscowet* is 52.8 feet long, has a 14.5-foot beam and 6-foot draft, and is powered by a 170-H.P. diesel engine. She has a 10-KW, AC main electrical generator and a 7.5-KW, AC auxiliary; she accommodates five people. Each vessel has a cruising speed of 10.5 MPH and a cruising range of about 1,000 miles.

Both vessels are of all-steel welded construction, and are equipped with modern navigation, operating, and scientific equipment. The general appearance and deck arrangement of the vessels are very similar. The forward part of the main deck houses an enclosed and heated laboratory that is provided with the necessary equipment for handling biological specimens and for those analyses of lake water which must be made without delay.

The laboratory also houses a gill-net lifter used to retrieve a wide variety of experimental gill nets that may be set on the bottom, suspended at mid-depths or set obliquely from the surface to the bottom. The other principal fishing gears are various types of bottom and mid-water trawls towed from a large winch located on the open afterdeck. Electrically-powered winches are used to handle bathythermographs and other hydrographic instruments, small tow nets, and plankton nets that sample minute plankton organisms and larval fish.

Vertical temperature measurements are obtained with bathythermographs having depth ranges to 50, 200, 450, and 900 feet. These instruments record on smoked glass slides the temperature of water at various depths while the vessel is underway. More accurate measurements of surface and subsurface temperatures are recorded by electrical resistance thermometers or reversing thermometers. The reversing thermometers are mounted on the case of a water sampler known as a Nansen bottle. This sampler can take water from any depth desired. It has valves at each end that close as it and the attached thermometer are inverted by a tripping mechanism. A sample of the water at that precise depth is thus enclosed and brought to the surface for analysis.

Petersen (clam shell) and "orange-peel" dredges are used to collect bottom organisms and samples of the lakes sedi-

The *Siscowet* is stationed at Ashland. This vessel and the *Cisco* have been used in studying the fish population of Lake Superior.

ments. On occasion, geologists use the main winch and boom to operate coring devices that penetrate and sample the bottom sediments.

Radar and a depth recorder on each vessel aid in the accurate location of stations and in navigation during unfavorable weather. The depth recorder has a magnifier attachment to aid in detecting and identifying schools of fish.

Since her launching in 1951, the *Cisco* has been in each of the Great Lakes except Lake Ontario. In 1951, the *Cisco* made a shake-down cruise in Lake Michigan to test her navigational and scientific equipment. The main accomplishment of this cruise was an exploration of the bottom sediments which provided information for the description of the Lake Chippewa low-water stage of Lake Michigan a few thousand years ago when the lake was 350 feet below the present level. During 1952, the vessel was an important tool in a study of the lake herring of Green Bay, Lake Michigan. She also made exploratory cruises into Lakes Huron and Superior. Full-season studies of the early life history of the lake trout and the limnology of Lake Superior followed in 1953. In 1954 and 1955, the *Cisco* was used in Lake Michigan to obtain information on the effects of the sea lamprey and the disappearance of the lake trout on the chub population. During 1956, the *Cisco* participated in a fishery and limnological survey of Saginaw Bay and southern Lake Huron. This survey included a special study of the currents and limnology of Saginaw Bay made in cooperation with the Michigan Department of Conservation.

DURING 1957–58, the *Cisco* served as a key vessel in a study of the fishery and limnological problems of Lake Erie. The schedule of the *Cisco* was closely coordinated with the operations of the several Lake Erie states and the Province of Ontario.

From 1952 until her reconversion in 1957, the *Siscowet* was based on Lake Superior at Marquette, Michigan, and used in limited fishery surveys and for stocking lake trout. After reconversion was completed in 1958, she was attached to the Lake Superior laboratory of the Bureau of Commercial Fisheries, at Ashland, Wisconsin.

The *Siscowet* was used in 1958 to gather information on stocks of lake trout, on the habits of lake herring and whitefish, and on the features of their environment in the western third of Lake Superior.

IN VIEW of the strong possibility that the sea lamprey soon may be under control in Lake Superior, it is important that a base of reference be established from which to describe changes in the abundance, distribution, and composition of fish stocks that may occur as the numbers of sea lamprey decline. To provide the widest coverage possible in establishing this base, the *Cisco* and the *Siscowet* worked in Lake Superior during 1959.

Standard gangs of gill nets are set at several locations in the Apostle Island region and at Isle Royale by the *Siscowet*, and in Keweenaw Bay, off Marquette and Grand Marais, and in the Whitefish Bay region by the *Cisco*. Mesh sizes in each gang range from 1 to 5 inches (stretched measure) by ½-inch intervals. Gangs are fished at depths of 15, 25, 50, 75, and 100 fathoms (90, 150, 300, 450, and 600 feet) wherever possible. Catches provide information on the distribution, abundance, species and size composition of the fish population.

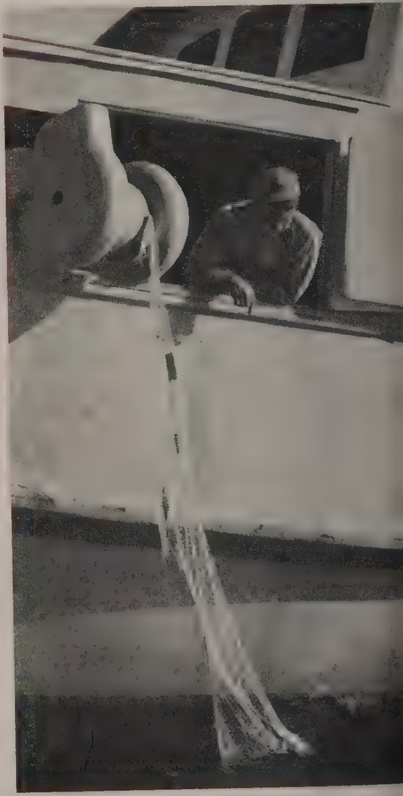
Fish too small to be taken in gill nets are sampled with trawls that have ½-inch-mesh (stretched measure) cod ends. Fine mesh bobbinet is added to the cod ends if very small fish are present. Larval (newly hatched) fish are collected in fine-mesh plankton nets attached to bottom trawls or towed at mid-depths. Nets to catch small fish are used mainly in shallow water, but some are towed in deep water to sample sculpins and small chubs (deep-water ciscoes) which are important food of lake trout.

Lake trout and species associated with them receive primary consideration in the Lake Superior studies. As the sea lamprey population is reduced, the lake trout and associated species should show the effects of the reduction. There should be a demonstrable tendency toward the "pre-lamprey" conditions. Knowledge of the abundance of the various age and size groups of lake trout will show the proportion of planted fish in the population, and will indicate how long artificial stocking should continue. These guides are essential to sensible planning of lake trout rehabilitation.

Although the *Cisco* may operate in another lake after 1959, the *Siscowet* will continue to gather information in Lake Superior. Qualitative and quantitative measures of changes in the fish population will be possible from the data collected. Continuing measurements of the abundance and composition of fish-food organisms, and the physical and chemical characteristics of the water will help us understand their influence on the survival, growth, and abundance of fish. In time, this information may provide clues to the causes of wide fluctuations in abundance that characterize many fish stocks. Better evaluation of the impact of new species such as the smelt and alewife on the native fish will be possible.

STUDIES of little-known but important life-history stages of various species are undertaken by the *Siscowet* as opportunity permits. For example, the spawning times and places of the species of chubs are inadequately known. Since differences in spawning time are important in distinguishing them, more information will aid in their accurate identification. Information will be obtained on differences in growth rates of whitefish and round whitefish (menominee or pilot) in local populations. Their spawning habits and requirements will also be determined. The distribution and growth of the lake herring and the growth and food of the smelt will also be investigated.

Operation of these research vessels has contributed, and will continue to contribute, the knowledge needed to understand and to administer properly the fisheries of the Great Lakes. These and other vessels used in fishery research on the Great Lakes cannot cover adequately the vast expanses of all the lakes, but their operation makes it possible to collect more comprehensive data than we have had in the past. With each item of information they accumulate, we come closer to wiser use of the fishery resources.



Here, on the *Cisco*, experimental gill nets brir up evidence on the status of lake trout ar associated species. Plans are to trace chang in the fish population as the sea lamprey brought under control.

A New Hawaiian Engraulid Fish

DONALD W. STRASBURG

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A New Hawaiian Engraulid Fish

Donald W. Strasburg[1]

The oceanic skipjack or aku (*Katsuwonus pelamis*) is commercially the most important fish in the Hawaiian Islands. This tuna is captured by pole and line, using live bait as chum. Of the several species of small fish employed as bait, the endemic anchovy known as nehu (*Stolephorus purpureus,* family Engraulidae) forms the major skipjack bait resource. Its importance in this respect has made the nehu the subject of several studies, resulting in reports on its food habits (Hiatt, 1951), spawning (Tester, 1951, 1955), oxygen requirements (Pritchard, 1955), meristic variation (Tester and Hiatt, 1952), and taxonomy (Gosline, 1951). Biologically, the nehu is probably the best-known fish in the Hawaiian Islands.

The nehu is a carnivorous anchovy, living and breeding in estuaries and bays. It is captured by seine during the day, and by a combination of seine and electric light at night. The nehu has been regarded as neritic except for two puzzling circumstances: the nehu population in Maalaea Bay, Maui, is periodically augmented by incursions of fish apparently from the open sea, and eggs differing only slightly from those of nehu were once taken in the offshore waters of Oahu (Tester, personal communication).

During the summer of 1958 the research vessel "Charles H. Gilbert" of the U. S. Fish and Wildlife Service encountered several large schools of anchovies 5–30 mi. off Oahu. Samples were presumed to be nehu and were not preserved. Later, conversation with commercial fishermen revealed that, while not regularly occurring, such schools were not rare, and also that the fish differed from nehu in both color and shape. Some fishermen termed these fish "oki-iwashi," which is literally translated as "pelagic sardine-like fish," while others referred to them as "roundheads." The latter name was descriptive of the short head which caused the fish to be gilled in seines used for nehu.

Thinking that this offshore anchovy represented either a different species or an ecological variant of nehu, we intensified our efforts to obtain specimens from areas removed from the inshore nehu grounds. Ultimately, two small collections were obtained, one through the interest of Captain Noboru Tsue of the M/V "Buccaneer," the other from biologists of the Territorial Division of Fish and Game (Honolulu). Examination of these specimens proved them to be not only distinct from nehu but also new to science. It is the purpose of this paper to describe and distinguish this new Hawaiian anchovy.

In addition to the collectors, thanks are due also to Drs. Albert L. Tester and William A. Gosline of the University of Hawaii, the former for making available meristic data for nehu, the latter for examining specimens of *Anchoviella mauii.* I am also grateful to Mr. John G. Simpson of the Inter-American Tropical Tuna Commission for data on Central American *Anchoviella.*

METHODS

All meristic data were enumerated from specimens stained with alizarin. Articulated and nonarticulated fin rays were not differentiated, and those rays split to a single base were counted as single rays. All gill rakers, including rudiments, were counted from the first arch on the right side. Distinction between the upper and lower limbs of gill arches was made on the presence of 1–3 rakers with bases embedded in connective tissue between the two portions of the arch. Because most specimens had lost their scales, the number of scale rows was obtained by counting the scale pockets. The only measurement needing description is maxillary length, which was taken as a straight line between the

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[1] U.S. Fish and Wildlife Service, Honolulu, Hawaii. Manuscript received February 4, 1959.

FIG. 1. Distinguishing features of Hawaiian engraulid fishes. Compare head length, maxillary length, and pectoral–pelvic interspace. *a, Stolephorus purpureus; b, Stolephorus buccaneeri.*

snout tip and the most posterior portion of the maxillary.

In a recent paper on the scientific name of the nehu, Gosline (1951) mentioned several problems incidental to the use of the term *Stolephorus,* and pointed out the need for a comparison between this genus and the related *Anchoviella.* Although both species of Hawaiian engraulids are referable to *Stolephorus* (Gosline, 1951; Weber and de Beaufort, 1913; Jordan and Seale, 1925, 1926), it is desirable to define this genus as exclusively as possible, for it has not been possible to undertake the needed study of the several engraulid genera. As it is here understood, *Stolephorus* includes those engraulid fishes having separate anal and caudal fins, the dorsal origin anterior to that of the anal, normal upper pectoral rays, bony scutes on the mid-ventral line, maxillaries not extending posterior of the gill opening, and a silvery stripe lengthwise on the body. The genus lacks canine teeth and free spines preceding the dorsal fin (spines are sometimes present in *S. tri* and *S. baganensis* (Hardenberg, 1933*a*)). As far as is known, the species of *Stolephorus* are Indo-Pacific in distribution. The Hawaiian forms can be distinguished from each other by characteristics presented in the following key, Figure 1, and Table 1. Differences between the new species and its congeners are mentioned in the species diagnosis.

KEY TO THE HAWAIIAN ENGRAULIDAE

1. Pectoral and pelvic fins far apart, distance between tip of depressed pectoral fin and pelvic base equal to twice eye diameter; maxillary short, failing to reach anterior edge of preopercle by a distance equal to ½ to ⅔ pupil diameter, maxillary length contained in head length 1.4–1.7 (usually 1.6) times; head short, its length contained 4.1–4.7 (usually 4.1–4.5) times in standard length..........................Roundhead. ***Stolephorus buccaneeri,*** new species
2. Pectoral and pelvic fins close together, distance between tip of depressed pectoral and pelvic base equal to ¼ to 1 eye diameter; maxillary long, just reaching anterior edge of preopercle, its length contained in head length 1.0–1.3 (usually 1.3) times; head long, its length contained 3.4–4.0 (usually 3.5–3.8) times in standard length ....Nehu. *Stolephorus purpureus* Fowler

Stolephorus buccaneeri, new species
Figs. 1, 2

HOLOTYPE: USNM no. 177742, a male, 53.3 mm. in standard length, taken by seine 200 yd. west of Lehua Island, Niihau, Hawaiian Islands, on September 15, 1958, by Captain Noboru Tsue and crew of M/V "Buccaneer" of Honolulu.

PARATYPES: USNM no. 177743, 19 specimens, males and females, 44.7–58.9 mm. in standard length, taken with holotype; USNM no. 177744, 8 specimens, 40.5–51.5 mm. in standard length, taken from stomach of *Euthynnus yaito* captured 1 mi. off Makua, Oahu, Hawaiian Islands, on September 10, 1958, by Territorial Division of Fish and Game biologists aboard the M/V "Makua" of Honolulu.

DESCRIPTION: Counts made on *S. buccaneeri* are recorded in Table 1, and detailed measurements of the holotype and two paratypes appear in Table 2. Dorsal rays 13 or 14; anal 14–16, the last base usually with 2 rays; pectoral 14–17; pelvic 7; principal caudal rays 9 + 1 + 9; branchiostegal rays 11–13; gill rakers 16 or 17 + 2 or 3 + 23 or 24 (total 41–43); scales in a longitudinal series 41–44, in a transverse series 9(?) or 10(?); scutes on mid-ventral line

TABLE 1
COUNTS MADE ON HAWAIIAN SPECIES OF *Stolephorus*[1]

	DORSAL RAYS		ANAL RAYS		PECTORAL RAYS		PELVIC RAYS		PRINCIPAL CAUDAL RAYS, *buccaneeri*	BRANCHIOSTEGAL RAYS, *buccaneeri*	SCALE ROWS		VENTRAL SCUTES		GILL RAKERS	
	buccaneeri	*purpureus*	*buccaneeri*	*purpureus*	*buccaneeri*	*purpureus*	*buccaneeri*	*purpureus*			*buccaneeri*	*purpureus*	*buccaneeri*	*purpureus*	*buccaneeri*	*purpureus*
0....	—	—	—	—	—	—	—	—	—	—	—	—	—	5	—	—
1....	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
2....	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—
3....	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	—
4....	—	—	—	—	—	—	—	—	—	—	—	—	14	3	—	—
5....	—	—	—	—	—	—	—	—	—	—	—	—	5	1	—	—
6....	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—
7....	—	—	—	—	—	—	19	40	—	—	—	—	1	—	—	—
10....	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
11....	—	1	—	—	—	—	—	—	—	9	—	—	—	—	—	—
12....	—	8	—	—	—	10	—	—	—	7	—	—	—	—	—	—
13....	21	126	—	—	—	77	—	—	—	3	—	—	—	—	—	—
14....	9	82	6	5	17	175	—	—	—	—	—	—	—	—	—	—
15....	—	2	19	55	18	65	—	—	—	—	—	—	—	—	—	—
16....	—	—	5	113	7	11	—	—	—	—	—	—	—	—	—	—
17....	—	—	—	43	2	2	—	—	—	—	—	—	—	—	—	—
18....	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—
19....	—	—	—	—	—	—	—	—	22	—	—	—	—	—	—	—
38....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
39....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
40....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
41....	—	—	—	—	—	—	—	—	—	—	1	1	—	—	2	2
42....	—	—	—	—	—	—	—	—	—	—	3	2	—	—	3	11
43....	—	—	—	—	—	—	—	—	—	—	1	5	—	—	5	14
44....	—	—	—	—	—	—	—	—	—	—	1	3	—	—	—	35
45....	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	41
46....	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	36
47....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	25
48....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18
49....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	16
50....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7
51....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2

[1] Most data for *purpureus* were supplied by Tester. Both pectoral and pelvic fins were counted, except for the pectorals of some *purpureus*.

2–7 (usually 3–5); vertebrae 43 including urostyle (1 specimen).

Head 215–257, snout 44–59, bony interorbital 48–58, postorbital head length (horizontal) 100–130, maxillary length 141–168, eye diameter 54–79, snout to dorsal origin 473–534, snout to anal origin 672–730, snout to pelvic base 431–504, snout to anterior pectoral base 220–264, longest dorsal ray (2nd or 3rd ray) 119–168, longest pectoral ray 114–145, maximum depth 152–208, least depth of caudal peduncle 75–98, maximum width 112–140 (all measurements as thousandths of the standard length, based on 22 specimens).

Teeth fine, noncaninoid, uniserial on premaxillary, maxillary, and mandible, in small patches and rows on palatines and hyoids, reduced to asperities on vomer; head naked, skin rugose in parietal region; opercle and preopercle without spines; pseudobranchiae well developed; both surfaces of gill rakers finely denticulate; mouth relatively small; posterior tip of maxillary smoothly rounded dorsally, truncate ventrally, failing to reach anterior margin of preopercle by ½–⅔ pupil diameter; posterior tip of mandible bluntly pointed, just reaching anterior edge of preopercle; ventral profile slightly curved, the ventral mid-line moderately compressed; scutes restricted to region between pectoral and pelvic fins, each with a posteriorly projecting spine and a riblike lateral ramus nearly reaching a pleural rib; caudal forked, the sixth ray from the top and bottom with a fleshy alar flap.

Scales deciduous, cycloid, with 11–13 radiating striae, the anterior 2 or 4 sometimes connecting centrally; anterior scale margin not crenulate; anterior half of scale with fine, parallel, dorsoventral grooves, posterior half with coarse crescentic grooves; an elongate alar scale above pectoral base, none (?) at pelvic base.

Ovarian eggs from a 49.3 mm. maturing female were oval and measured about 0.5 by 0.3 mm. These eggs were whitish and opaque and showed no signs of an oil globule when stained with Sudan IV.

Color in formalin straw or white with a silvery band lengthwise from eye to caudal base, band about ⅔ eye diameter in width at eye and on caudal peduncle, but as wide as eye beneath dorsal fin; tips of snout and mandible blackish, a spray of fine black dots on occipito-parietal region; dorsalmost scale pockets margined in black, particularly on caudal peduncle; dorsal and caudal rays black-spotted, a row of 14 or 15 black spots along anal base.

In life *buccaneeri* is said to be purplish blue, in contrast to *purpureus* which is greenish or brownish.

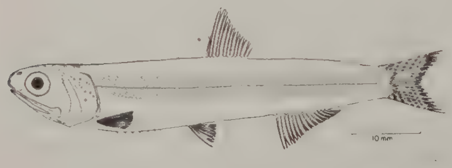

FIG. 2. Holotype of *Stolephorus buccaneeri*, new species (USNM no. 177742) from Lehua Island, Niihau, Hawaiian Islands.

TABLE 2

MEASUREMENTS, EXPRESSED IN THOUSANDTHS OF THE STANDARD LENGTH, MADE ON *Stolephorus buccaneeri*

	HOLOTYPE	PARATYPE	PARATYPE
Standard length (mm.)	53.3	49.8	55.3
Head length	250	215	230
Postorbital length of head	140	124	121
Eye diameter	67	60	54
Interorbital width	51	52	51
Snout length	46	48	49
Maxillary length	164	147	141
Maximum depth of body	187	169	181
Least depth of body	79	76	78
Maximum width of body	137	116	132
Snout to dorsal origin	529	488	528
Snout to anal origin	717	701	691
Snout to pectoral base	258	255	241
Snout to pelvic base	492	452	472
Longest dorsal ray	142	147	134
Longest pectoral ray	105	135	127
Sex	male	female	male

AFFINITIES: Comparative material of the numerous species of *Stolephorus* was not available, and the relationships of *buccaneeri* were determined almost solely from the literature. All nominal species referable to the genus (as defined above) were considered insofar as possible, but some poorly described forms could not be allocated, nor did descriptions always agree between authors. The authors cited below provided the information by which the species were separated. The order of presentation is not necessarily phylogenetic nor fully dichotomous.

Probably most distantly related to *buccaneeri* are those species of *Stolephorus* having the maxillary extending to the gill opening or nearly to it: *commersoni, waitei, rex, tri, baganensis,* and *insularis* (Jordan and Seale, 1926; Weber and de Beaufort, 1913; Fowler, 1941; Hardenberg, 1933*b*). Another distinctive group includes *evermanni* and *indicus,* both of which have the pectorals reaching or nearly reaching the pelvic bases (Jordan and Seale, 1906, 1926). According to Weber and de Beaufort (1913), the pectoral fins of *indicus* do not reach the pelvic base, but in their material the anal origin was below the middle of the dorsal base, whereas in *buccaneeri* the anal origin is slightly posterior to the rear of the dorsal base. *S. insularum, extensus, holodon, chinensis, nasuta,* and *aestuaria* differ from *buccaneeri* in having 20 or more anal rays (Jordan and Seale, 1926; Fowler, 1941);

and *heterolobus, pseudoheterolobus, zollingeri,* and *purpureus* differ in having the maxillary length contained 1.0–1.4 times in the head length, as opposed to 1.4–1.7 times for *buccaneeri* (Hardenberg, 1933*b;* Fowler, 1941). *S. celebicus* is listed by Hardenberg (1933*a,* 1933*b*) and Fowler (1941) as lacking scutes, and would therefore be excluded from this discussion were it not for the fact that *S. commersoni* occasionally also lacks these structures (Hardenberg, 1933*a*) as does *purpureus* (Table 1). The phylogenetic importance of scutes has been stressed by Jordan and Seale (1925, 1926), but it appears that their variation must be understood before they can be used to effect generic separation.

Some mention must also be made of *Anchoviella mauii.* Although described as new from Maui, Hawaiian Islands (Fowler and Bean, 1923), this species has since been synonymized with *Engraulis australis* by Fowler (1934), who also pointed out that the specimens were mislabeled as to locality.

DISTRIBUTION: *S. buccaneeri* has been collected only from the waters off the northern Hawaiian islands of Oahu and Niihau, and its true distribution is unknown. It also remains to be demonstrated whether schools of offshore anchovies are composed of *buccaneeri* or of *purpureus* or of both. Examination of a collection of anchovies from Maalaea, Maui (where the population is thought to be augmented from offshore stocks), revealed only *purpureus.* Judging from the place of capture of one type series (200 yd. from shore), *buccaneeri* also may be neritic.

REMARKS: It is a pleasure to name this new anchovy *buccaneeri* after the M/V "Buccaneer" of Honolulu. It is suggested that "roundhead" be used as a common name to distinguish this fish from nehu.

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DONALD W. STRASBURG
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PROGRESS IN OBSERVING TUNA UNDERWATER AT SEA

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Progress in Observing Tuna Underwater at Sea

By

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1. Introduction

The world's increasing demand for protein food makes it imperative that we improve the efficiency of harvest for those resources whose crops are not easily manipulated. In the central Pacific such a resource is oceanic skipjack, *Katsuwonus pelamis* (L.), a small surface-schooling tuna which is one of the most valuable seafoods in the area. Studies of larval skipjack (MATSUMOTO, 1958) and adults (IKEHARA, 1953; MURPHY and IKEHARA, 1955; WILSON and AUSTIN, 1959) indicate the species to be widespread and locally abundant, but in spite of this it is not exploited to the extent warranted by world demand. One factor limiting its capture is bait fish (TESTER, 1951; YAMASHITA, 1958), for most skipjack are caught by live-bait methods, and the bait species are usually delicate and in short supply. In the central Pacific these conditions restrict the fishery to waters adjacent to baiting grounds, and for these and other reasons the resource in large portions of the open ocean is untouched (SCHAEFER and REVELLE, 1959). A promising approach to the problems of increasing fishing efficiency, developing baitless techniques of capture, and exploiting new bait species is the understanding of skipjack behaviour as it is related to the fishing method. This subject, especially the equipment developed during our studies of it, forms the basis for the present report.

To obtain data on behaviour it was first necessary to devise a method of making underwater observations. A study of captive skipjack seemed to be precluded by earlier failures to maintain these fish in ponds and tanks (TESTER, 1952), and, in addition, it was desired to study their behaviour under fishing conditions. Placing an observer or a recording device beneath the surface from a fishing vessel was a logical solution to the problem.

2. Method of Fishing for Skipjack

An account of the present Hawaiian skipjack fishery has been given by JUNE (1951). Suffice it to say that commercial fishing is done from the sterns of 60–80 ft motor vessels from which skipjack schools are located by means of

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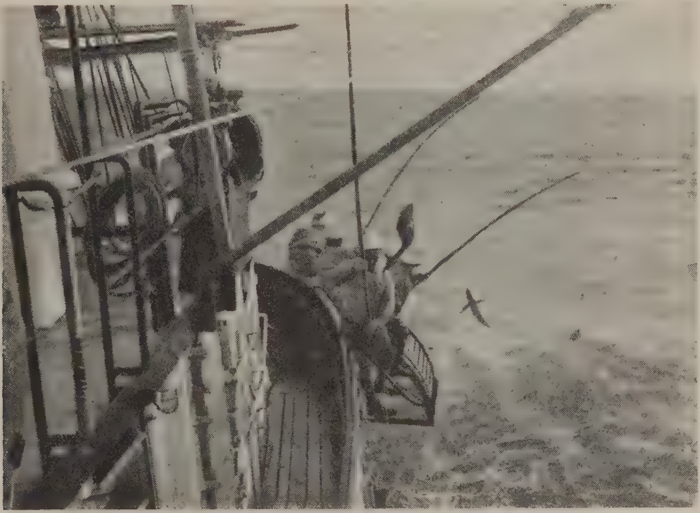


Figure 1. Tuna fishing from the port side and stern of the "Charles H. Gilbert." Small yellowfin tuna are being caught here, but the same technique is used for skipjack.

the accompanying bird flocks. The birds and tuna prey in common on small fish and squid, and, in order to engage the tuna, live-bait chum is used to divert them from their natural food. During fishing, sprays of water are directed into the sea around the stern where, according to the fishermen, they enhance the effects of the bait.

The HBL research vessel "Charles H. Gilbert", a 112 ft steel-hulled ship, was designed for a variety of research tasks including skipjack fishing. A view of the port side of this ship, looking aft, is given in Figure 1; four men occupy the two side fishing racks, while the pole of a fifth man is visible in the third (stern) rack. Above them, and partly obscured by pipework, is the "chummer" whose station is on top of a large baitwell, whence he throws live baitfish into the water near the fishermen's lures. The rack framework is composed of pipes carrying water for use as spray; a spraying nozzle is visible near the second fisherman's knee. Because of such factors as chum abundance, wake and stream flow effects, and possibly propeller noise, there is a gradient in fishing activity. Action is greatest beneath the closest fisherman in Figure 1 and least at the stern. For behaviour study purposes attention was focused on activity beneath the two side racks.

3. Evaluation of Observation Equipment

Ladder and diver

Our first attempt to place an observer underwater took place in June 1957. Because of the exploratory nature of the study, equipment was inexpensive and simple: A diver made observations from a 10 ft steel ladder on the ship's port side.

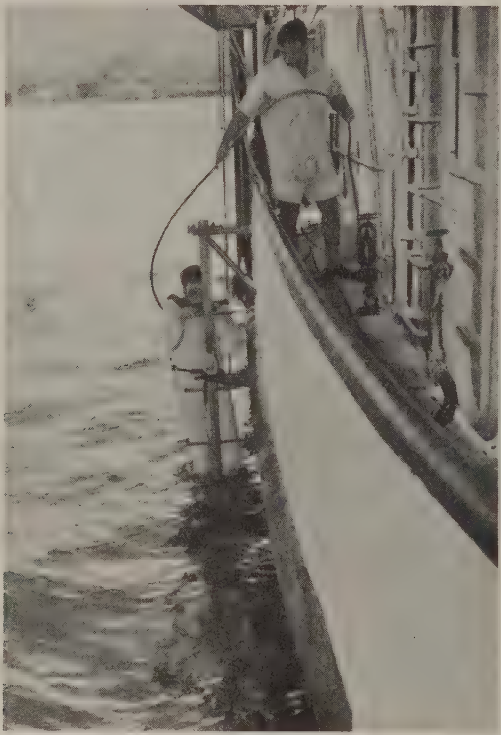


Figure 2. Diver descending overside ladder of "Charles H. Gilbert."

As shown in Figure 2, the diver was equipped with a face mask, mouthpiece, regulator, and hose leading to a bottled air supply on deck, a weighted belt, and protective diving clothing. He descended the ladder and crouched on its lower rungs, facing aft. Depending on his stance, his eyes were 1–2 ft beneath the surface. He carried a 16 mm Cine camera in a waterproof case, and between dives made voice records of his impressions. There was no provision for communication except a system of knocks on the ship's hull or ladder. The ladder itself was a 2 in. steel pipe with welded rungs of $\frac{1}{2}$ in. steel bars. Three brackets held it to the ship while in use, and at other times it was pivoted out of the water as shown in Figure 3.

The diver-ladder technique was used only in bays, but it provided answers to several questions. It told us that a diver could be effectively positioned beneath the ship, and that bubbles from propeller cavitation were not a serious hindrance to his vision. Its cheapness and simplicity made this method a qualified success; its defects are listed below.

The method's principal disadvantages involved the diver's safety, utility, and comfort. The ship had to be slowed or stopped in order for him to ascend or descend the ladder, and once he was in place, speeds greater than about 3 knots tended to tear the mask from his face. The current, the ship's roll, and

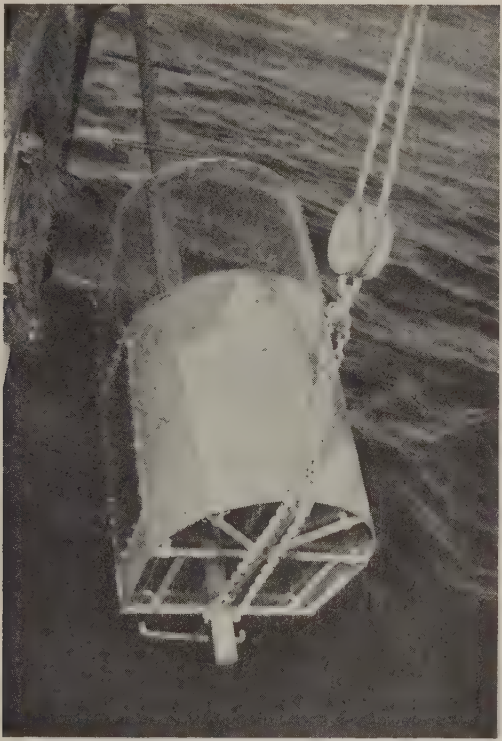


Figure 3. Shield used to protect diver on overside ladder.

ladder vibrations were sometimes sufficient to require his using both hands to remain on the ladder, thus prohibiting picture taking. The current rapidly chilled him, in spite of protective woolen and rubber clothing, and it also caused sore jaws from biting the regulator mouthpiece against the current's drag. Bubbles exhaled by the diver or dragged down around the ladder from the surface tended to obscure vision. There was an important time loss when he ascended to replace the film in his encased camera or to record his observations. Last, but certainly not least, was the psychological effect of being completely exposed during fishing in waters where sharks are common.

A solution to some of these problems was offered by partially enclosing the diver in a 4 × 2 × 2 ft U-shaped steel and plastic shield (Figures 3 and 4). Besides protecting him from the current and sharks, this provided a more comfortable place to sit. Squatting or kneeling on the transparent floor of the cage, he could photograph in response to knocks from the surface indicating a change of bait, etc. His forward and lateral vision was through windows of ½ in. transparent plastic; facing aft, where the skipjack were concentrated, there was nothing intervening except two ladder rungs. The shielded ladder was tested several times from June to August, 1957. These tests were quite rewarding, and following them it was decided that construction of a more permanent observation platform was warranted.

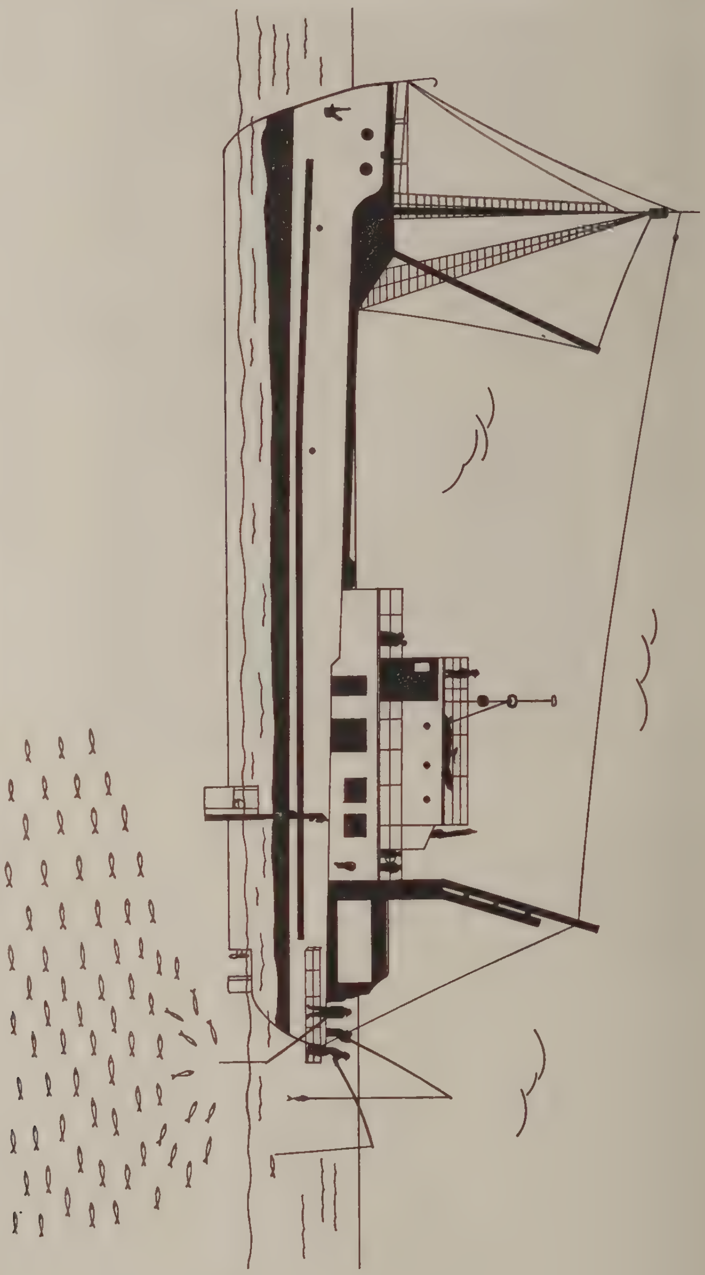


Figure 4. Position of shielded ladder and diver during skipjack fishing.

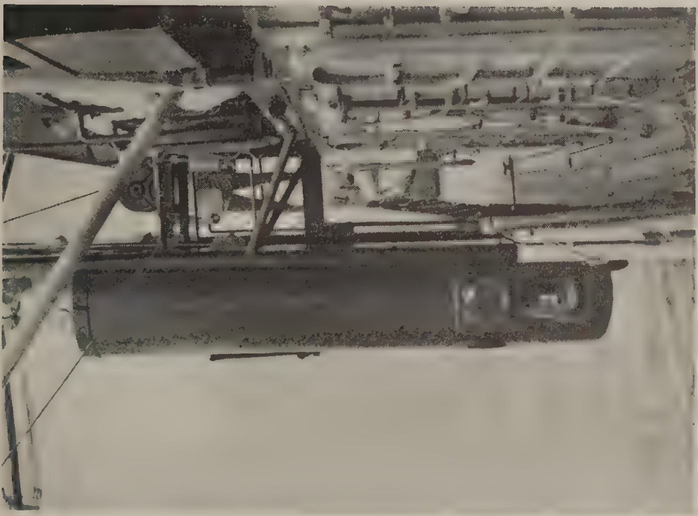


Figure 5. Observation caisson hauled from water after fishing.

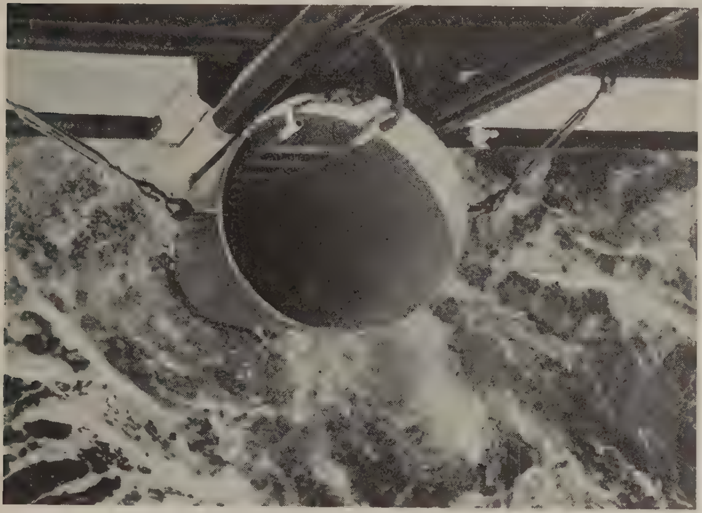


Figure 6. Caisson in its fully lowered position.
Note turbulence and bubbles.

Overside caisson

Many of the unsatisfactory aspects of the 1957 apparatus were inherent in the use of a diver. During the succeeding winter, therefore, plans were made for placing an observer beneath the surface in a retractable air-filled cylinder. Such a device was built in the spring of 1958, and was extensively tested on the "Charles H. Gilbert" during May-July. Observations made from this caisson have been discussed by STRASBURG (1959) and STRASBURG and YUEN (in press), but the apparatus itself has not been described.

As originally constructed (Figure 5), the caisson was a 11½ ft tube, open at the top, with four ports at its lower end. Just prior to fishing this tube was partially submerged by means of pulleys and a hand crank; after fishing it was raised from the water by its own buoyancy and the same pulleys attached in a different manner. The caisson was movably fixed to the ship by two 6 ft T bars which bore against the inside of extra-heavy slotted 4 in. pipes (Figure 6). A short length of pipe on the bottom of the caisson provided rigidity by fitting into a gudgeon 6 ft below the waterline. Accidental bobbing-up of the caisson was prevented by shackles, sister hooks, and turnbuckles securing it to the ship's rail in the lowered position (Figure 6).

An observer reached the viewing ports of the submerged caisson by a ladder. With his eyes 4 ft below the surface, he sat on a low stool and took moving pictures from a 5 in. forward port (½ in. plastic), a 12 in. side port, or two 10 in. after ports (side and after ports of ¾ in. glass). Communication with the surface was via a speaking tube leading to a recorder microphone. Fresh air was blown to the bottom of the caisson by way of one of the ladder's sidepieces (Figure 6). Water splashing over the top or leaking around the window seals accumulated beneath a false bottom, whence it could be drained by a valve or aspirated by a hose. In practise, except in all but flat calm seas, it was necessary to cover the top with a wooden hatch (not shown) to prevent flooding.

Some other statistics of the caisson are of interest in evaluating its utility. Its walls were of welded ¼ in. steel plate, and were not quite circular in cross section, being 28 × 30 inches in outside dimensions. The empty weight was about 1350 lbs. Water drag gradually misaligned the T bar bearings and their pipe guides, so that increasing amounts of time, up to 10 minutes, were required for lowering. This resulted in a costly pause, in terms of bait expenditure, while the crew hammered and tugged at the recalcitrant caisson. With the caisson lowered, the ship cruised at 7·5 knots instead of its normal 9, making it difficult to approach fast-swimming tuna schools. Even at this reduced speed bubbles blocked all vision except from the forward port. Dense clouds of bubbles were drawn down around the caisson and tended to collect in the recessed faces of the ports. At speeds of 2–3 knots (usual fishing speeds) turbidity was reduced to an occasional but annoying swirl of bubbles. Horizontal visibility was about 100–150 ft, depending on the object, but skipjack could be distinguished from other tuna species only to about 60 ft.

The caisson, as described above, was used to evaluate the effects of several fishing variables (dead bait, water sprays, various bait species, chumming rate, and sound) on skipjack feeding behaviour. Five weeks of such experiments provided ample opportunity for appraising the caisson. Turbidity provided the biggest problem, for bubbles sometimes rendered as much as 75% of the Cine camera film useless for detailed analysis. Another annoying feature was

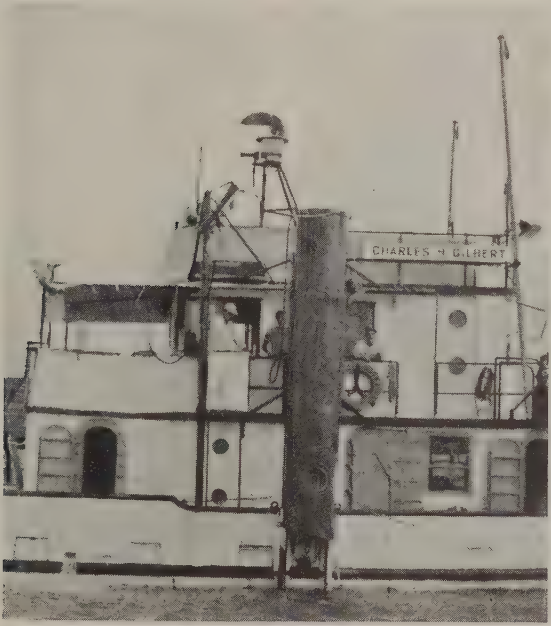
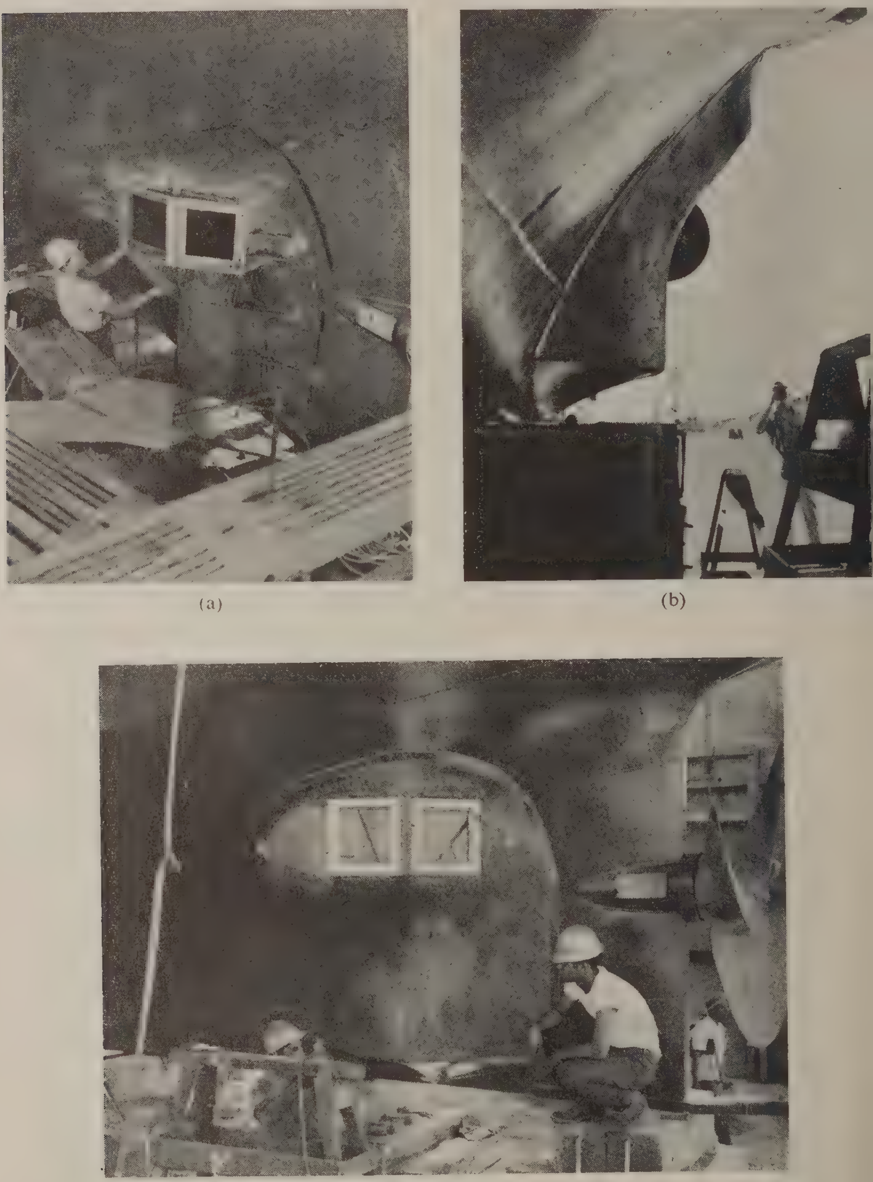


Figure 7. The redesigned observation caisson.

salt water splashing on the observer or his equipment, even with the top of the caisson covered (heavy seas sometimes opened the cover, drenching the observer). A third unfavourable feature was the restricted vision aft, where both ports were small and one slanted downward and was seldom used. Few tuna schools were lost because of the ship's stopping to lower the caisson, but this did happen occasionally and was not desirable. The advantages of the caisson over the preceding ladder are obvious and require no discussion.

The "Charles H. Gilbert" was engaged in other duties in mid-summer, 1958, so the caisson was temporarily removed and modified. Its height was increased by adding a 4 ft section to the top (Figure 7), and portions of the slotted pipe guides were removed in an attempt to reduce bubble formation. The two after ports were replaced by a single 12 × 24 in. pane of $\frac{1}{2}$ in. plastic. The hand crank for raising and lowering the caisson was removed, and power for doing this was instead supplied by the anchor winch. The improved 1600 lb caisson functioned satisfactorily during the period August–November, 1958. The added height kept out all water, and the enlarged after window gave increased latitude for picture-taking. The caisson could be lowered rapidly, often in $1\frac{1}{2}$ minutes, and there was little time loss from this factor. Shortening the pipe guides had no appreciable effect on turbidity, however, and this feature continued to be the most serious drawback to the caisson's use. By November 1958, it was decided that bubble-free vision was sufficiently important to justify new observation instruments.



(a) (b)

(c)

Figure 8. (a) Fabricating metal portions of stern blister. (b) Profile view of stern blister. Windows are at vertical upper edge of blister. (c) Side view of completed stern blister. Windows and concrete fairing have been added.

Stern blister

An obvious means of reducing bubble interference was to place a window in the ship's hull below the waterline. This was regarded as a last resort, for it meant possibly weakening the vessel, relinquishing space needed for fuel, and perhaps reducing the ship's speed and steering qualities by the drag resulting from a protuberance. Nevertheless, in June 1959, the "Charles H. Gilbert" was placed in drydock and a convex observation "blister" added to the hull in communication with a former fuel compartment. Stages in the fabrication of this installation are shown in Figure 8.

Space for the observer was provided by welding a steel semi-cylinder, 22 in. in diameter and 3½ ft high, to the ship's skin outside the former fuel tank (Figure 8a). Surmounting this cylinder was a wide sill on which the observer could rest his arms or equipment. This sill was fronted by two 12 × 12 in. windows of 1 in. glass set 7 ft below the waterline. Steel reinforcing provided anchorage for an outer concrete coating which was sprayed on in liquid form, and hardened as a 1 to 12 in. layer which streamlined the blister. The completed structure, shown in Figures 8b and c, held two people, but only one could look out conveniently. The blister's bulge was minimal, and the ship cruised at 9 knots as before. Steering at normal cruising speed required no rudder compensation, but when maneuvering slowly, as in docking, the bow tended to starboard.

Observers enter the blister through a covered vertical access-way on the after main deck. A ladder and a series of steps lead to the semi-cylinder, where they can stand or sit comfortably. They and their equipment are dry at all times, and forced draft ventilation makes the blister one of the more pleasant places aboard ship. The previous bubble-turbidity problem is entirely eliminated, and objects such as sheets of newspaper or masses of *Sargassum* can be seen near the surface up to ranges of about 200 ft. Typical skipjack activity as seen from the blister is shown in Figure 9.

The blister was employed extensively during July–September, 1959. Observation from it was so easy, and occasionally so enjoyable, that in addition to experimental tests of skipjack behaviour, data were obtained on animals attracted to submerged lights, luminescent organisms, plankton net operation, composition of windrows of phytoplankton, underwater feeding of seabirds, and animals associated with drifting logs. Observations could have been made on bottom conditions and the undersides of waves.

As constructed the blister had two faults: its proximity to the tailshaft and propeller resulted in a high noise level, and its permanently submerged windows quickly became covered with sessile marine life. Noise ceased to be an important problem when sound-powered telephone headsets were used, and window cleaning required only a few minutes of a diver's time about twice a week.

Television

Concurrently with the first blister tests, we explored the use of closed-circuit television for studying tuna behaviour. Information was desired on the utility of a television camera mounted in the blister and another suspended over the side in a waterproof case. Skipjack activity recorded by these means was compared to that seen directly by eye, and to that recorded by a Cine camera

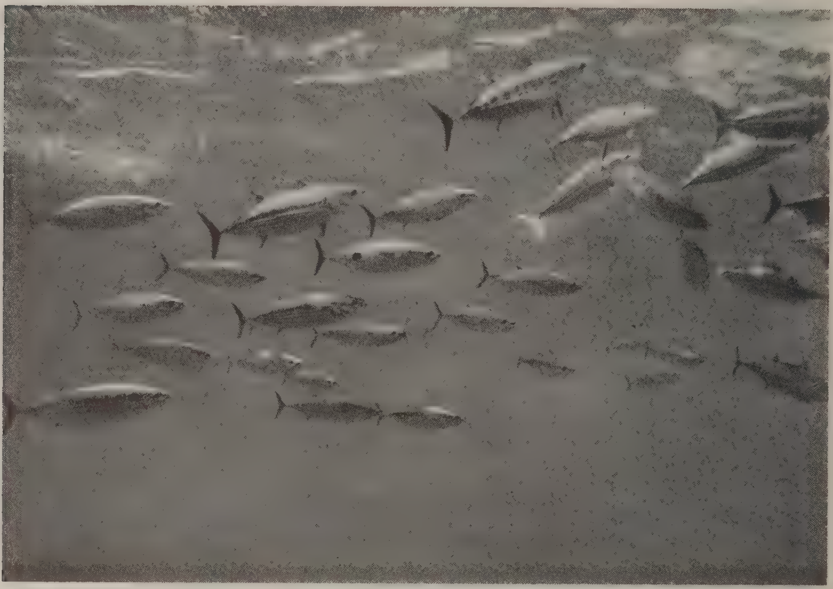


Figure 9. School of oceanic skipjack seen from the stern blister.

using colour film. Because only monochromatic television equipment was available, black-and-white Cine films were taken of the television screens.

An encased Vidicon television camera was attached to a rigid pipe framework and lowered over the side of the "Charles H. Gilbert" to the depth of the blister windows. Operations were coordinated, and fish scenes were observed, televised, and photographed simultaneously. Using 525 scan-lines per second and a 10 in. screen, the televised presentation was inferior to the eye's view. With television, fish outlines were indistinct, species could not be distinguished, contrast between fish and background was poor, portions of the screen were black, and a full-time technician was required to operate the controls. Substantially the same thing was shown by comparing the filmed versions of this, but here television appeared to have greater depth of field, and therefore more fish were visible. This virtue was offset by fluctuations in brightness and erratically moving horizontal bars, both possibly being synchronization phenomena. Television did not detect the numerous small animals swarming around a submerged light at night, but proved remarkably sensitive for observing bottom life. When the encased camera was lowered to the bottom in 92 ft of water, algae (*Padina*) and fish (*Acanthurus*) were easily identified, even during the rapidly changing light conditions preceding sunset.

Simultaneous operation of television and film cameras from within the blister was only partially successful. Apparently the ship's vibration affected the television camera, so that bright bars sporadically obliterated images on the screen. Exclusive of this, Cine camera or visual observation was still superior to the televised version.

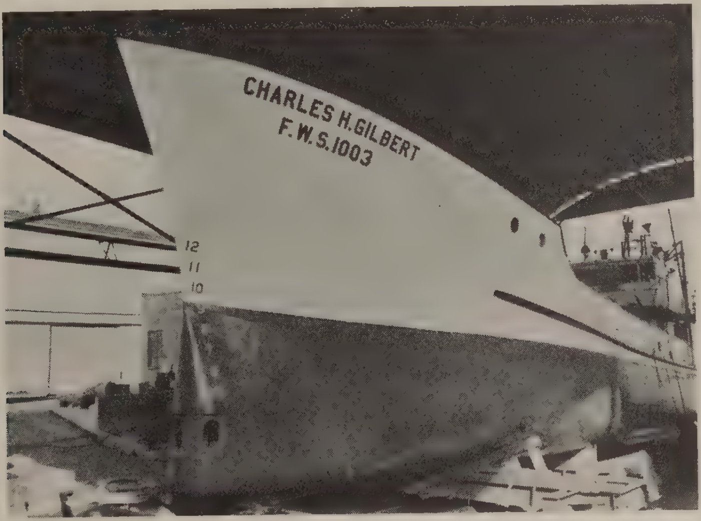


Figure 10. Construction of the bow blister on the "Charles H. Gilbert."

Bow blister

Although well adapted for observing feeding behaviour, the stern blister was too near the center of fish activity for out-lying skipjack to be seen. Thus we only suspect, and do not know, that the members of feeding aggregations are constantly leaving as they become satiated, and are constantly being replaced by hungry fish, the entire phenomenon being associated with a deep-swimming body of non-feeding fish. The physical dimensions and numbers of fish in a feeding aggregation are similarly difficult to ascertain. More information on these points could be obtained if the blister could be maneuvered around a school being fished by another ship. It is possible to do this with the stern blister but it will be much more easily accomplished with a similar structure located in the bow.

At this writing the "Charles H. Gilbert" is being fitted with the bulbous bow and observation blister shown in Figure 10. This blister is equipped with three 12 × 18 in. oval windows of 1 in. glass, behind which the observer will lie. His head will be 7 ft beneath the waterline, and his working space a long, high compartment, 3 ft wide. Access to the bow blister will be by ladder from the forecastle storage spaces, and communication is by sound-powered telephone. Ventilation is forced-draft.

4. Future Plans

An outstanding limitation of all the above approaches is that information is gained only about skipjack at or near the surface. Nothing is known of their activities at depths greater than about 100 ft, although there are indications that these activities may be significant. We have evidence (unpublished) that schools are attracted downward, in competition to our chum, by schools of natural food such as squid. Also, several hundred hours spent searching the surface layers from the stern blister have failed to reveal any really small skipjack. Fish weighing a pound or less should be much more numerous than the adults, and it can be surmised that they occur at depths greater than we can see.

For these reasons we are presently investigating the feasibility of constructing a small, fast, highly manœuverable submarine for studying skipjack behaviour to depths of about 400 ft. As envisioned, schools of adults would be located at the surface and followed downward, and underwater searches would be made for sizes not occurring at the surface. Observations would be by eye and camera through forward ports, and by television cameras facing in other directions. Acoustical apparatus and lights would aid in locating fish beyond visual range. Additional missions might include collecting plankton and water samples under selected conditions of depth, temperature, light intensity, or salinity; studies of biological sound, etc. An obvious failing of this method would be the near-impossibility of actually capturing skipjack, but this would be offset by the wealth of other information obtained.

5. Acknowledgements

Several members and former members of the Honolulu Biological Laboratory (HBL) staff participated in the design and use of underwater observational equipment. Mr. G. I. MURPHY initiated the investigation with an underwater ladder carrying a diver. MURPHY, V. E. BROCK, and the writers subsequently developed a dry caisson, and in the following years BROCK and the writers designed hull blisters and worked with underwater television. Messrs. H. J. MANN and A. K. AKANA, by drawing plans, fabricating models, and supervising construction, were closely involved with all such equipment, and their help is gratefully acknowledged. The photographs used in Figures 2 and 3 were supplied by the Honolulu Star-Bulletin.

6. Summary

Equipment for studying tuna behaviour underwater on the high seas is described. Starting with a ladder and diver, the staff of the Honolulu Biological Laboratory has progressed to a shielded ladder, an overside caisson, stern and bow blisters, and underwater television. Future plans involve a small, fast submarine. The principal faults and virtues of each device are noted.

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METHODS OF ENUMERATING SALMON IN ALASKA

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The purpose of this paper is to discuss the various methods currently used or being developed by the Bureau of Commercial Fisheries in Alaska for enumerating adult and juvenile salmon.

Successful management of Alaska's salmon resources is dependent upon accurate prediction and subsequent assessment of the size of salmon runs returning to spawn. Predicting the magnitude of returning runs and manipulating the catch and escapement require a continuous inventory of salmon during various stages of their life history.

Five species of Pacific salmon are fished commercially in Alaska: king, *Oncorhynchus tshawytscha;* red, *O. nerka;* pink, *O. gorbuscha;* coho, *O. kisutch;* and chum, *O. keta.* Most of the research effort directed toward perfecting methods of enumeration, however, has centered on the two most commercially important species, red and pink salmon.

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[1] In the absence of the chairman, Discussion Leader Bartholomew presided.

ADULT ENUMERATION

The size of a returning salmon run is usually determined by adding the commercial catch to the escapement. The relationship between escapement and return has formed the principal basis for predicting returning runs. In certain areas of Alaska, estimates of the daily escapement play a critical role in management of the fishery. In the Bristol Bay region, the largest producer of red salmon in the world, and on Kodiak Island, daily counts are made of salmon as they ascend the main rivers to the lakes.

Weirs and Towers

Until recently weirs constructed across several of the trunk streams that lead to the spawning grounds provided the only means of obtaining the day-to-day escapement estimates necessary for management of the Bristol Bay fisheries. Because of the expense and time required in construction and maintenance of weirs, the number of rivers that could be covered in this way was limited. Estimates of the escapements on unweired rivers were based on aerial surveys of the spawning grounds, carried out in accordance with methods described by Kelez (1947) and Eicher (1953).

Red salmon, in ascending the main trunk streams, characteristically migrate next to the banks within a few feet of shore (Figure 1). Early workers in Bristol Bay made use of this characteristic by making visual counts of salmon at irregular intervals from high banks, particularly on the Egegik River. Their assessment of the runs, however, was qualitative rather than quantitative, indicating only that the runs were larger or smaller than those of prior years. Weirs, whenever and wherever used, provided the only reliable means of obtaining a quantitative measure of the escapements until the early 1950's.

In 1953, the Fisheries Research Institute of the University of Washington erected portable towers on the banks of the Wood River. The towers afforded ready observation of the migration paths of adult salmon, and sample counts were made at regular intervals throughout the season; thus, a quantitative estimate of the Wood River escapement was possible for the first time since 1919 when the weir was removed.

To test the reliability of the tower method of enumeration, the Bureau made comparisons between tower and weir estimates on the Egegik River in 1956 and the Naknek River in 1957. In both years, towers located 1 to 2 miles above the weirs provided estimates of the escapements that agreed closely with the estimates gained by operation of the weirs.

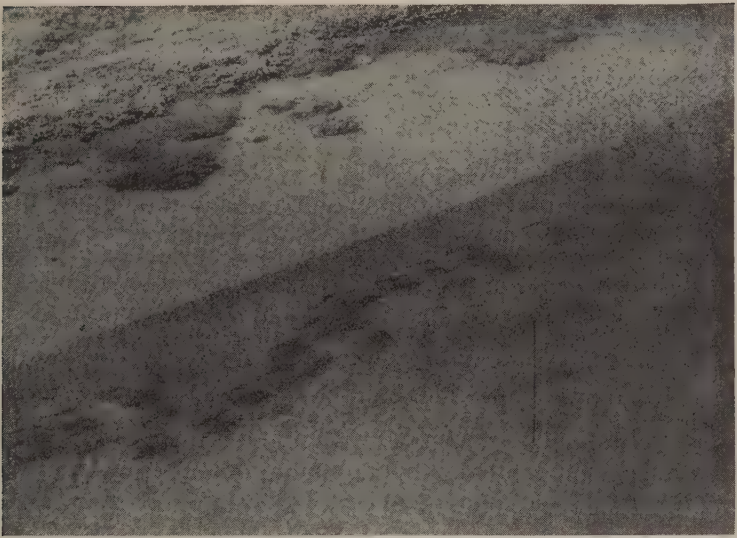

Figure 1. Migrating red salmon, Egegik River, 1956 (view from tower).

For the period July 12-30, 1956, when comparable tower and weir counts were attempted on the Egegik River, weir operators estimated the escapement at 1,064,000 red salmon. An estimate based on the upstream tower counts indicated the escapement for this period was 985,000, 7.4 percent lower than the weir estimate. Much of the difference occurred on July 16 and 17, when tower estimates were lower than weir estimates by 15,000 and 73,000 respectively. On these days fish passed through the left side of the weir for the first time during the season, and it was not until noon of the second day that a tower could be erected on the left bank to obtain counts of fish moving up this side of the river. Omitting the two days, the total estimate from tower counts was only 1.6 percent lower than the weir estimate.

During the period from June 29 to July 31, 1957, comparable weir and tower counts were obtained on the Naknek River. Weir operators estimated an escapement of approximately 631,000 red salmon, while tower operators estimated an escapement of approximately 712,000, 12.8 percent more than the weir estimate. Most of the difference between tower and weir counts occurred on July 8 and 9, during the peak of the run, when the tower estimates were 51,000 and 25,000 higher than weir estimates. Much of this error was attributed to the development of leaks in the weir during this period. This was borne out by the fact that tower personnel observed large numbers of fish in the early morning, several hours before the weir gates were opened. If the counts for the two days are omitted from the comparison, the estimated total based on tower counts was only 0.9 percent higher than that obtained at the weir.

Tower estimates of the Egegik and Naknek River escapements in 1956 and 1957 were considered to be sufficiently accurate to warrant discontinuing the costly weir program in Bristol Bay. Removal of weirs, however, posed new problems, not the least of which was that of gauging the extent of night migration. The fishing season is short in Bristol Bay and, during its height, periods of darkness vary in length from 3 to 6 hours, depending upon atmospheric conditions.

In the normal operation of weirs, the counting gates are closed at night and enumeration is discontinued until morning. The shift to observation towers necessitated developing satisfactory lighting arrangements which would not unduly disturb the normal nocturnal migration of salmon and which would permit a suitable assessment of their numbers.

Extensive lighting experiments were conducted on Bristol Bay rivers in 1958. Several methods employing sealed beam flood and spot lights of 300 to 600 watts were tried both above and below the water surface. The arrangement that proved most satisfactory was one in which the light source was located on shore not more than 5 feet above the surface of the water, with the beam of light directed downstream at an angle of 45° to the bank. The light was set so the beam hit the water surface about 10 feet from shore. This resulted in a darkened area next to the river bank. Migrating fish entering the illuminated area tended to lead toward shore along the downstream edge of the beam and pass through the darkened area, where there was enough diffused light to permit visual counts.

Measures to improve visibility during daylight hours included: (1) use of Polaroid glasses; (2) placement of light-colored 4-by 8-foot hardware cloth panels on the river bottom across the migration path; and (3) anchoring of floating, fence-like structures upstream from the towers to dampen surface turbulence over the counting areas.

The techniques used in enumerating salmon from towers, while not perfect, have reached a routine operational stage. At present each tower station is manned by three people, with one observer on duty at all times during the season. Counts are made for 10 minutes out of each hour on both the left and right banks of the river. Estimates of the total number of fish in the escapement are obtained by simple expansion of the sample counts. Preliminary analysis indicates that

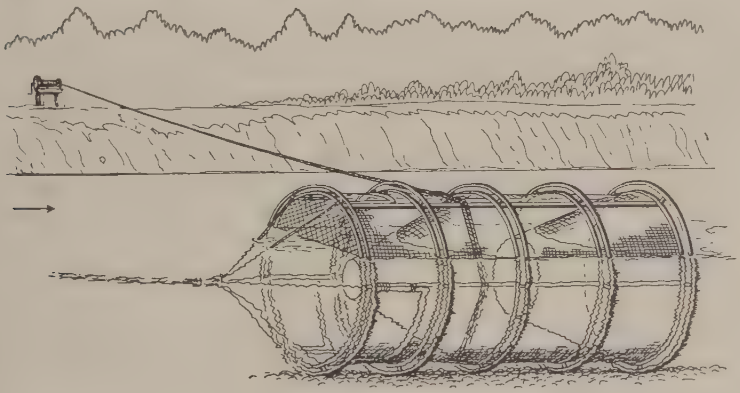

Figure 2. Wire fyke trap used on the Kenai River.

10-minute sample counts will yield estimates of the escapement within 3 to 5 percent of that which might be obtained by a total count.

Fyke Trapping

Many rivers in Alaska are of glacial origin and extremely turbid, precluding the use of visual counts. This is particularly true in the important red salmon producing area of Cook Inlet. Here, studies were conducted on the Kenai River from 1957 to 1959 to develop a method of obtaining indices and estimates of the daily escapement through test-fishing.

The gear used was cylindrical wire fyke traps that were 10 feet in diameter and 18 feet in length (Figure 2). They were similar to those developed by the California Department of Fish and Game (Hallock, Fry, and LaFaunce, 1957) for use on the Sacramento River to estimate adult salmon and steelhead trout runs. Traps of this type were also used by the Oregon Fish Commission on the Snake River in Oregon to estimate king salmon and steelhead trout runs.

Two index traps were fished in the same location each year, one on each side of the river. A one-quarter-inch wire rope, securely attached at one end to a longitudinal stringer of the trap, was wrapped around the trap several times. The other end of the rope was attached to a hand winch. Operation of the winch retrieved the trap from the river by rolling it shoreward and upward on the bank. Launching the trap consisted of simply pushing it into the river. Once started, it rolled into position through its own momentum.

Traps were emptied twice daily, the salmon were counted and tagged, and certain biological information was obtained. Results of these studies indicated that fyke traps were effective in capturing fish in proportion to their numbers in the swift, turbid waters of the Kenai River. There was close agreement between daily catches in each trap. There was also close agreement between the commercial catch of red salmon and the fyke trap catches, both in timing of the run and characteristics of the curve of abundance. Since traps did not appear to fish selectively for red salmon of a particular size range, sample catches could be used to assess certain characteristics of the escapement, for instance, age-group structure, sex ratio, and size of individual fish.

Estimates of the total number of red salmon in the escapements to the Kenai River, based on tagged to untagged fish ratios, proved of little value chiefly because of difficulty in establishing a satisfactory method of tag recovery.

Visual Aerial and Surface Surveys

In the important pink salmon producing areas of Southeastern Alaska, Prince William Sound, and the Alaska Peninsula, the large number of streams precludes the use of towers or weirs, except in a few cases in support of biological studies. Frequent aerial surveys of the spawning grounds during the fishing season afford the quickest and most economical means of obtaining an immediate estimate of the numbers of fish which have escaped the fishery.

The techniques currently employed follow closely those developed by Kelez (1947) for use in Bristol Bay and are described in some detail by Eicher (1953). Best results are obtained with aircraft having a long range and providing good visibility downward on either side, and which can be safely flown at speeds of 100 miles per hour or less at altitudes varying from 500 to 800 feet.

Essentially the method employs a two-man team—a pilot and a trained or experienced observer. During a survey run on a stream or beach spawning area, the pilot keeps the observer in continual visual contact with the fish and maintains the correct altitude while the observer makes his count or estimate.

On sparsely populated streams the fish are counted individually. However, on the majority of streams the observer counts in groups or blocks of 10, 100, or 1,000 fish.

The usual procedure followed when an estimate of the total escapement to a particular spawning area is desired, is to visit that area several times during the season. This assures that observations will be made during the peak of spawning when the bulk of the escapement can be most easily counted. It is characterized by widespread spawning and few schooled or dead fish.

On small streams surface or foot surveys provide a more accurate means of censusing salmon, but the excessive cost of this method limits its use. Occasionally surface surveys are used in place of aerial survey on important streams that cannot be adequately covered by aircraft. These are usually streams that are hidden from the aerial observer's view by overhanging trees and brush.

Usually a two-man team is used when covering a stream on foot. Methods of counting vary with the concentrations of fish. In most instances the fish are counted individually on a hand tally by each member of the party. After completing a survey of a stream or section of a stream, the counts by each man are totaled and the average is taken as the count for the area.

JUVENILE ENUMERATION

Predictions based on the relationship of adult returns to parent spawners have, at times, proved discouraging, primarily because of widely varying survival rates. A more reliable basis for prediction would be gained if the numbers of juvenile salmon that migrate to sea were known. Information of this nature is necessary to determine the survival rates from egg to migrant stage.

Red Salmon Smolt Enumeration

Investigations have been under way on several rivers in Bristol Bay since 1956 to develop a reliable and economical method of assessing the annual seaward migration of red salmon. Preliminary studies were designed to learn the daily and seasonal timing of the outmigration, how the smolts were distributed in relation to water depth, velocity, and cross-section of stream, and their ages and relative size. Knowledge of these features was considered essential to the development of adequate sampling equipment and techniques.

Efforts have been directed toward randomly sampling on a 24-hour basis an entire cross section of the Naknek, Egegik, and Ugashik Rivers, using fyke nets to capture smolts (Figure 3). Fyke nets of this design had been used by the Fisheries Research Institute on the Wood and Kvichak Rivers in Bristol Bay to obtain an annual index to the red salmon outmigration.

On the Naknek River a three-eighth-inch galvanized steel cable 720 feet in length was strung across the river bed from bank to bank. The cable was divided into fifteen 48-foot increments. Each division was designated as a fishing site. Head lines of three-eighth-inch manila rope were attached to the cable to mark the 16-foot, center

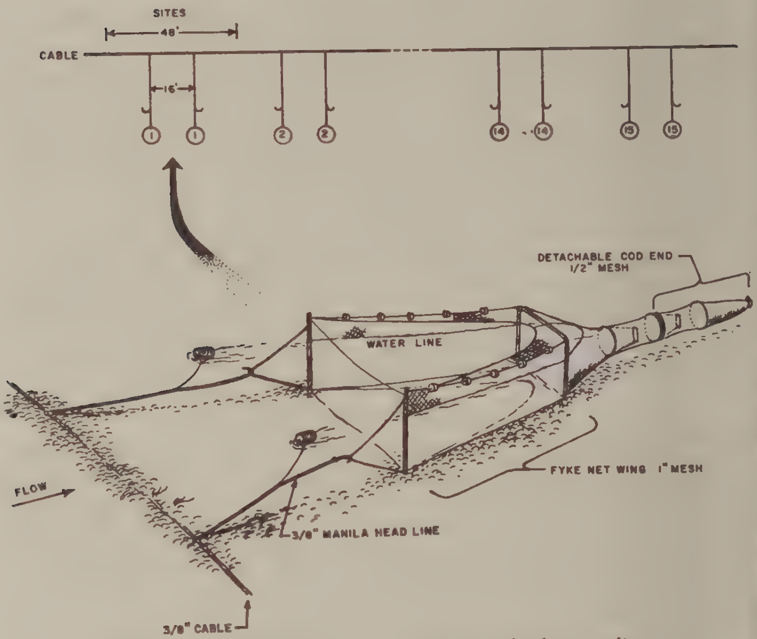
SITES
48'
CABLE
16'
1
1
2
2
14
14
15
15
DETACHABLE COD END
1/2" MESH
WATER LINE
FLOW
FYKE NET WING 1" MESH
3/8" MANILA HEAD LINE
3/8" CABLE

Figure 3. Fyke net set up used to enumerate red salmon smolts.

section of each site (Figure 3). The trailing end of each head line was buoyed to the surface with a spongex float bearing the number of the site. A fyke net could be quickly attached to any pair of head lines delineating a specific fishing site. Fyke nets were fished with an 8-foot opening, thus fishing only one-half of the center 16-foot section or one-sixth of the total area of the fishing site.

The sampling schedule was of Latin square design randomized with respect to sites, time periods within days, and days of season. All 15 sites are fished in random order each day for a specified period of time. Estimates of the total number of smolts are derived as follows:

$X = \frac{W}{F} PD \bar{x}$ where
W = width of river at trapping station
F = width of fyke net opening
P = number of fishing periods within day
D = number of days in trapping season
$\bar{x}$ = average catch per standard fishing period

It should be emphasized that estimates based on fyke net catches probably are low because fish avoided the nets. The degree to which smolts may evade capture in various velocities remains to be evaluated. Casual observations led to several general impressions: (1) In the lower velocities encountered at points away from the main channels, smolts can and do swim out and around the wings of the nets; (2) larger fish are better able to evade capture; (3) the efficiency of fyke nets approaches 100 percent in velocities of 5.5 feet per second and higher; and (4) the ability of smolts to avoid capture might vary, also, with changing light intensity in a manner now unknown. Until these relationships can be definitely established, the estimated totals must be regarded as underestimates whose principal value is that of being amenable to statistical treatment in evaluating annual differences in smolt abundance.

Pink Salmon Fry Enumeration

Salmon research in Prince William Sound and Southeastern Alaska has included development of sampling and trapping techniques to estimate the abundance of pink salmon fry produced in streams and intertidal areas.

To sample fry abundance in streams, rectangular fyke traps (Figure 4) capable of fishing from top to bottom of the stream, are placed at regular intervals across the width of the stream. The traps are anchored in the stream by means of two pipes suspended from a wooden catwalk or driven into the stream bed. Trap arrays are usually located far enough upstream to be above the influence of tides and are fished continuously throughout the fry run.

The percentage of migrating fry caught in a set of traps is determined through mark and recovery experiments. In early trials fry were anesthetized and marked by fin-clipping. This method prohibited the marking of large numbers of fry and made visual examination of large catches for marked fish exceedingly difficult and time consuming.

In 1958 and 1959, fry were marked with neutral red stain. The most successful staining combination was a mixture of stain and water at concentration of 1:300,000 in which fry were immersed for seven hours. Fry remained stained at least 72 hours after being removed from the solution.

Staining was considered superior to fin-clipping since the fry do not have to be anesthetized and large numbers can be marked simultaneously. The rediddsh-colored fry are easily distinguished from the unstained in separating marked from unmarked.

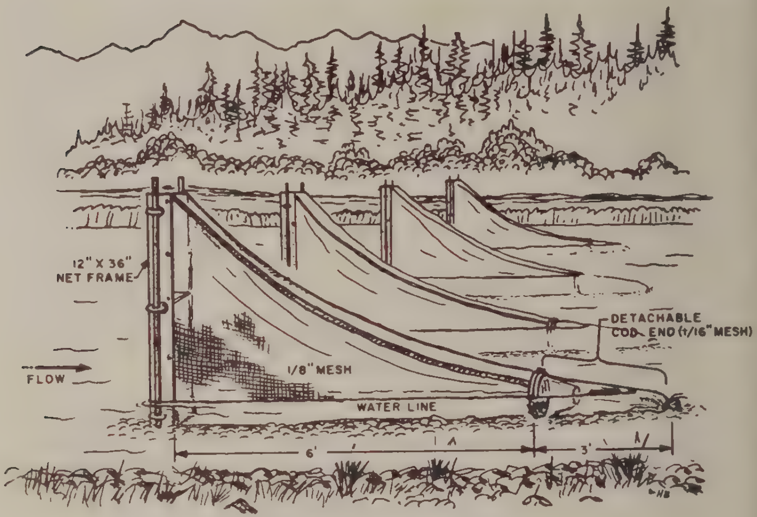

Figure 4. Array of pink salmon fyke traps.

Production in Intertidal Areas of Streams

To estimate the abundance of fry in the intertidal areas of streams, a number of square-yard quadrats are sampled at random. The average number of pink fry, larvae, and eggs per unit area is applied to the intertidal zone to arrive at an estimate of the total.

Sampling is accomplished by excavating in the quadrats with an "egg pump," which was designed by the Fisheries Research Institute. The device is powered by a gasoline engine and forces a mixture of air and water through a hard rubber hose that is inserted in the gravel. The air forced into the gravel assures floatation of any fry, larvae, or eggs present. A heavy wire-mesh frame, open at one end, is used to outline the sample quadrats. The fry, eggs, and larvae are carried by the current into the collecting net located immediately downstream from the open end of the frame.

SUMMARY AND CONCLUSIONS

The regulation of Alaska's salmon fisheries and the success of biological studies currently in progress are dependent to a great degree upon precise counts of migrating salmon at the adult, smolt, and fry stages of their life cycle.

Estimation of adult red salmon escapements from observation towers is sufficiently precise to warrant the widespread use of towers in Bristol Bay.

Large cylindrical fyke traps on the Kenai River are useful in obtaining an index to the abundance of red salmon adults in turbid Alaskan streams.

Aerial surveys are the most economical and quickest method of obtaining immediate estimates of the escapement in Southeastern Alaska and Prince William Sound.

On small streams, surface or foot surveys are more accurate than aerial surveys for estimating the size of spawning populations. Their principal use is on streams where aerial surveys are not feasible or where a greater degree of accuracy is needed.

Fyke nets are fished in Bristol Bay in accordance with a prearranged schedule to obtain an estimate of red salmon smolts.

Arrays of rectangular fyke traps are used in Southeastern Alaska and Prince William Sound streams to estimate the total number of pink salmon fry produced.

A successful method of temporarily staining fry with neutral red is superior to fin clipping in mark and recovery experiments.

Random sampling of the intertidal stream's spawning areas with an "egg pump" provides a means of estimating the fry production where trapping methods are not possible.

ACKNOWLEDGMENTS

The author wishes to acknowledge the helpful advice and assistance in preparation of this paper given by Charles DiCostanzo, Chief of Red Salmon Investigations, Bureau of Commercial Fisheries in Alaska. The author is also indebted to Jerry Hout, James Kirkwood, and Loyal Bouchard, individual project leaders of the studies described, for supplying some of the material used in this paper. Illustrations were prepared by Herb Bonnett.

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DISCUSSION

MR. LOGER [Michigan]: Have you made any examination of the stomachs of stream predators to learn about the increased predation on the young?

MR. STRATY: I don't believe so, as yet. I am not familiar with what the boys have been working on. However, I have not heard of any work done in that connection.

Mr. Cross [Kansas]: I too am interested in this stain; we did this with small fish of various kinds in some warm-water streams in our state and have had good success with a stain called ''Bismarck-Brown-Y,'' which held up for approximately two weeks.

Mr. Straty: I might say that the stain that we use was a neutral red and was used in a concentration of one part stain to 300,000 parts water in which the fry were immersed for about seven hours. They remained stained for about 72 hours after being taken out and transferred to fresh water. Of course, we tried a number of stains and we did have some mortality in connection with them. However, we are now using this neutral red.

Chairman Bartholomew: Have you ever considered the possibility of using lapse-time photography in your investigations towers so that you will not have to have three men on duty at all times?

Mr. Straty: I believe that the Fisheries Research Institute has done some work on numerating adult salmon by the use of photography. We, ourselves, have not done much with photography, although we have considered various methods of using it.

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STUDIES ON THE MORPHOLOGY AND LIFE-HISTORY OF *NOTOCOTYLUS MINUTUS* N. SP., A DIGENETIC TREMATODE FROM DUCKS

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U.S. Bureau of Commercial Fisheries

The U. S. Fish and Wildlife Service is perturbed because of the reduction in numbers of the soft-shelled clam, *Mya arenaria,* along the coast of New England (Glude, 1955). The writer is studying the parasites of the clam and of its predators (Stunkard, 1951, 1953, 1957, Stunkard and Uzmann, 1958) in an attempt to discover the causes of the decline and possible biological measures for control of the principal predators, the green and horseshoe crabs, *Carcinides maenas* and *Limulus polyphemus. Mya arenaria* harbors the asexual generations of digenetic trematodes, including the sporocysts and cercariae of *Cercaria myae* Uzmann, 1952. These larvae were shown by Stunkard and Uzmann (1958) to be developmental stages of a species of *Gymnophallus,* whose sexual generation occurs in shore-birds. The asexual stages invade the digestive and sexual organs of the mollusk, limiting or terminating its reproductive activity.

The clams also serve as intermediate hosts of other trematodes and 3 species of metacercariae occur commonly in the gills and palps. The life-cycles and bionomics of these worms are now under investigation. Since the asexual generations of these metacercariae must occur in mollusks which live in the immediate vicinity of the infected clam, an attempt is being made to find and identify them. Furthermore, since the definitive hosts of these metacercariae are animals that feed on *M. arenaria,* examination of shore-birds has been started. To obtain information on the sexually mature stages, metacercariae have been fed to laboratory-raised birds: chicks, eider ducks, herring gulls and common terns, as well as to mice and hamsters. The clams and other mollusks, the eider ducklings, and a sampling of shore-birds were provided by Walter R. Welch, Chief of Clam Investigations, Boothbay Harbor, Maine, under whose authority the study is conducted. Grateful appreciation is here expressed to him and members of his staff.

One of the most heavily parasitized snails is *Hydrobia minuta.* Examination of this snail disclosed infection by a notocotylid species, member of a group in which the cercariae encyst on objects in the water. The number of cercariae liberated by such a small snail is not large, the incidence of infection is low, about 0.1 to 0.2 percent, and since the larvae encyst soon after emergence, the finding of swimming cercariae is unusual. These cercariae encysted on the shells and opercula of *H. minuta* and on empty shells of *Gemma gemma* were fed to laboratory-reared gulls (*Larus argentatus*) and to eider ducks (*Somateria mollissima*). Adult worms recovered from the eider proved to be morphologically identical with others taken 30 years ago from the entrails of an unidentified duck and described by Stunkard

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and Dunihue (1931) as *Notocotylus gibbus* (Mehlis in Creplin, 1846). These specimens were assigned by Harwood (1939) to *Notocotylus imbricatus* (Looss, 1893), a species based on *Cercaria imbricata* Looss. It is now manifest that the worms do not belong to either *N. gibbus* or *N. imbricata;* they are described as a new species, *Notocotylus minutus.*

The measurements recorded are in millimeters.

Notocotylus minutus n. sp.
Syn. *Notocotylus gibbus* Stunkard and Dunihue, 1931.
Notocotylus imbricatus ex parte, Harwood, 1939.

The Adult (*Fig. 4*)

Sexually mature specimens measure 1.0 to 1.5 in length and 0.40 to 0.60 in width. The type specimen, shown in figure 4, from the cecum of a young eider duck, is somewhat flattened and measures 1.15 long and 0.50 wide. The body is flattened; the sides almost parallel; convex dorsally and concave ventrally. There are scattered bits of pigment in the anterior region as far back as the beginning of the metraterm. In the description by Stunkard and Dunihue (1931) the statement was made that there are 3 rows of ventral pits, 12 to 14 in each row. Harwood (1939), who studied those specimens, reported 15 in the median and 16 in the lateral rows. The worms had been taken from a duck, long dead, and were in poor condition. It is often difficult to determine the number of glandular pits on the ventral side of the body, especially at the posterior end which may be curved to form a cup-like lip that obscures the structure. In the specimen shown in the figure, there are clearly 16 pits in each of the 3 rows. Whether or not the number is variable or the apparent differences are merely the result of failure to see one or more of the structures is yet uncertain.

The oral sucker measures up to 0.12 in diameter; there is no pharynx; the esophagus is short and the digestive ceca are irregularly narrow in diameter. In the anterior half of the body they are median to the lateral pits while in the posterior portion they extend above the glands to the region of the gonads, where they turn mediad and pass between the testes and the ovary, terminating near the posterior end of the body.

The testes are situated on opposite sides at the posterior end of the body. They are deeply lobed, 0.20 to 0.25 long and 0.12 to 0.14 in greatest breadth. Ducts from the testes unite in front of the ootype to form a common duct which passes forward on the dorsal side of the body. It becomes coiled as it approaches the middle of the body and expands to form a seminal vesicle. Immediately in front of the uterine loops it enters the cirrus sac and may expand again inside the sac. The cirrus sac measures from 0.45 to 0.56 in length; the genital pore is below the esophagus.

The ovary is situated between the digestive ceca at the level of the testes. It is deeply lobed from 0.12 to 0.15 in diameter. The ootype complex and shell gland are located anterior to the ovary. The uterus extends in many transverse loops between the digestive ceca to the level of the posterior end of the cirrus sac, then forward beside the cirrus sac to the metraterm, which is about one-half the length of the cirrus sac. The eggs measure from 0.02 to 0.024 by 0.01 to 0.012; they bear long polar filaments at both poles.

The Redia (*Fig. 3*)

The rediae are sausage-shaped to cylindrical, often attenuated at one or both ends. Those with developing cercariae measure from 0.38 to 1.00 long and 0.14 to 0.30 in greatest width; others are smaller. The pharynx measures 0.028 to 0.034 in diameter; the intestine is short and saccate; it contains greenish to yellowish material, obviously digested snail tissue. The number of rediae in a snail is small, usually about a dozen, of different sizes. The small ones are motile, the larger ones lose motility as they become filled with progeny; however, the number of cercariae is relatively small, often only 1 or 2 cercariae and many younger stages in a redia.

The Cercaria (*Figs. 1, 2*)

The cercariae measure from 0.16 to 0.29 in length but can extend under pressure of a cover-glass to a length of 0.34. Ordinarily the width is about one-half the length, although the width varies inversely with the length as the larva elongates and contracts. The oral sucker is 0.023 to 0.026 in diameter although it becomes apparently larger under compression. The esophagus is about the length of the oral sucker and the ceca end blindly near the posterior end of the body. Brownish to blackish pigment begins to form in young cercariae, especially around the anterior end, and increases in amount as the larvae mature. There are 2 eye-spots, 0.014 to 0.017 in diameter, provided with lenses, and situated 1 on either side above the commissure of the nervous system. Concentration of pigment may at times suggest a smaller third one between the two. Strands of pigment extend backward, typically 3 on each side as shown in figure 1. There are gland cells which open near the oral sucker and many cystogenous cells, scattered throughout the body. The tail is small, typically thin and tapering, 0.03 to 0.035 wide at the base and 0.20 to 0.40 long. The tip of the tail may form a small muscular papilla. There are small locomotor pockets, situated ventrally on either side of the tail, but often completely hidden by the glandular cells that fill the area. The pattern of flame-cells and tubules was obscured by development of glands and only the major components of the excretory system were observed. The collecting ducts unite at the level of the eye-spots to form a finger-like projection which may extend to the level of the oral sucker. The ducts thus form a loop which becomes filled with concretions as the cercaria matures. The excretory vesicle is small and the common duct, formed by fusion of primary ducts, extends far into the tail where separation of the primary ducts restores 2 tubules which lead to the primary excretory pores (fig. 2). The form of the second vesicle, produced by fusion and enlargement of the collecting ducts, places this cercaria in the Yenchingensis Group of Miriam Rothschild (1938).

The Metacercaria (*Fig 5*)

The cercariae encyst soon after emergence and were taken from the opercula and shells of *H. minuta* and from empty, washed shells of *G. gemma.* The cysts are circular, 0.12 to 0.16 in diameter. They are flattened on the attached side and convex on the opposite side. The wall is 0.014 to 0.020 thick. The larvae do not grow in the cysts and measurements of the oral sucker were 0.024 to 0.029. The worms retain the pigment but the eye-spots are not distinct in specimens that have been encysted for some weeks.

DISCUSSION

Since the report by Stunkard and Dunihue (1931), knowledge of species in the genus *Notocotylus* has been substantially increased but the situation remains complicated and confused. By feeding young, parasite-free ducklings, L. and U. Szidat (1933) reported that *Cercaria ephemera* Nitzsch, 1807 from *Planorbis corneus* developed into adults which, in violation of the rules of nomenclature, they designated as a new species, *Notocotylus thienemanni.* They also reported that cercariae from *Lymnaea palustris* became adults which were identified as *Notocotylus attenuatus* (Rudolphi, 1809). The authors noted that in poorly preserved and distorted specimens it is difficult if not impossible to make accurate counts of the ventral glandular packets, but that in living specimens it is clear that the number and arrangement of these structures are constant and that they can serve as useful characters for specific identification. *Notocotylus gibbus* was redescribed. In this species the glandular packets are arranged with 11 in each lateral row and 4 larger ones in a median row. With the more complete description of *N. gibbus* it is apparent that the specimens described by Stunkard and Dunihue (1931) differ from that species in hosts and geographic distribution, in size of worms, size and shape of gonads, and in number and arrangement of glandular packets. Ursula Szidat (1935) fed larvae from *Bithynia tentaculata,* which were identified as *Cercaria imbricata* Looss, 1893, to chicks and ducks and recovered adults strikingly similar to *N. attenuatus,* but designated erroneously as a new species, *N. imbricatus.* The species was characterized by the small size of the cercariae and the identity of the intermediate host; Szidat remarked on the difficulty of distinguishing between these closely related trematodes on purely morphological grounds. Ursula Szidat (1936) insisted on the marked specificity of larval stages and the snail host, and listed 11 species of *Notocotylus.* She proposed a new genus *Barkeria* to contain *Notocotylus quinqueserialis,* an action that was anticipated by the erection of *Quinqueserialis* Skvortsov, 1935, and a new genus *Kossackia* to contain *N. gibbus.* Lal (1935) had named *N. gibbus* as type of a new genus, *Hindia.*

Harwood (1939) gave a comprehensive review of the subfamily Notocotylinae with keys to the genera and species. He discussed the morphology and taxonomy of species in the genus *Notocotylus,* rejected the proposed genera *Hindia* and *Kossackia,* and added 4 new species from North American hosts. Under the heading *Notocotylus imbricatus* (Looss, 1893), Szidat, 1935, Harwood included *Monostoma* sp. Stiles and Hassall, 1894; *Cercaria imbricata* Looss, 1893; *Notocotylus seineti* Fuhrmann, 1919; *Notocotylus urbanensis* Harrah, 1922, in part; *Notocotylus gibbus* Stunkard and Dunihue, 1931 (not Mehlis in Creplin, 1846); *Notocotylus intestinalis* Tubangui, 1932; *Notocotylus orientalis* Ku, 1937; *Hindia lucknowensis* Lal, 1935; and *Notocotylus anatis* Ku, 1937. A comparative table listed the characteristics of *N. imbricatus* from the various sources. Examination of that table discloses a heterogeneous collection of similar but not identical worms, from varied hosts and different parts of the world. The specimens described by Stunkard and Dunihue are distinct as the smallest members of the collection. *Notocotylus imbricatus* is based on *Cercaria imbricata* Looss as type. But the identity of *C. imbricata* is not clear. Miriam Rothschild (1940) pointed out that *C. imbricata* Looss, 1893, from *Paludina impura* (= *Bithynia tentaculata*) taken near Leipzig, Germany was named provisionally in a footnote without adequate description and, therefore, is a nomen nudum. Looss (1896) described as *C. imbricata* a cercaria from *Melania tuberculata* Egypt; the description of the species is concerned with the Egyptian and not the German cercaria. Miss Rothschild observed, p. 215, "It seems very probable that Looss' original surmise was correct, and that the cercaria he discovered in *Paludina impura* was the larval form of a *Notocotylus* identical with, or very closely related to, *N. attenuatus,* whereas the species from *Melania tuberculata* was the larval form of *Catatropis verrucosa.*" This opinion is supported by the report of U. Szidat (1935) who fed specimens from *Bithynia tentaculata* to chicks and ducks and obtained worms that were exceptionally like *N. attenuatus.*

Herber (1955) studied the life-history of *Notocotylus urbanensis* (Cort, 1914). He noted errors in the accounts of Barker (1915) and Harrah (1922); stated that the species described by Barker in the text as *Catatropis fimbriata* and figured as *Catatropis filamentis* and the species described by Harrah as *Paramonostomum echinatum* were based on poorly prepared specimens of *Notocotylus urbanensis* and that both names should be suppressed as synonyms. According to Herber, the specimens described by Harrah (1922) as *Notocotylus urbanensis* are not conspecific with *Cercaria urbanensis* Cort, 1914, but comprise a heterogeneous collection of immature specimens and the only one identified were referred to *Quinqueserialis.*

The determination of species in the genus *Notocotylus* is difficult. The worms are very similar and specific differences in morphology are small. Host specificity of the adult stages is not definite, because the same metacercariae can mature in a number of different host species. Apparently the snail hosts are more specific, and U. Szidat (1935) predicated precise specificity in *N. ephemera, N. attenuatus,* and *N. imbricata.* But there is so much confusion in the identification of larvae that final conclusions are impossible. No less than 4 different cercariae have been described as larvae of *N. attenuatus* by Joyeux (1922), Mathias (1930), L. and U. Szidat (1933), and Yamaguti (1938).

Although the identity of *N. imbricata* is yet problematical, it is clear that the worms described by Stunkard and Dunihue (1931) and those now at hand, whose larval stages are in the marine snail, *Hydrobia minuta,* are not identical with either of the species reported by Looss, that they are not members of *N. imbricata,* and represent a previously unnamed species, which is now designated *Notocotylus minutus.* The type specimen is deposited in the Helminthological Collection of the U. S. National Museum under the number 39,409.

SUMMARY

The asexual generations of a species of *Notocotylus* occur in the marine snail, *Hydrobia minuta,* in the region of Boothbay Harbor, Maine. Encysted metacercariae developed to maturity in a young, laboratory-reared eider duck. These worms are morphologically identical with others described by Stunkard and Dunihue (1931) as *Notocotylus gibbus* and assigned to *Notocotylus imbricatus* by Harwood (1939). New information discloses that the specimens cannot be assigned to either *N. gibbus* or *N. imbricatus,* and they are described as a new species, *Notocotylus minutus.* Redial, cercarial, metacercarial, and adult stages are figured.

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EXPLANATION OF PLATE

All drawings are of fixed and stained specimens, with certain details added from the study of living worms.

FIGURE 1. Cercaria, showing extent of pigmentation and position of the digestive organs; body of specimen, 0.2 mm long.

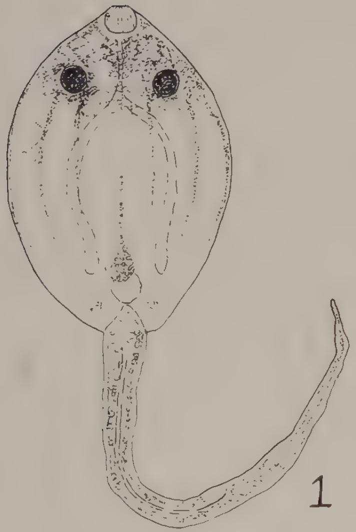
FIGURE 2. Cercaria, showing major features of the excretory system, the Anlagen of the gonads as a mass of germinal cells just anterior to the excretory vesicle, also the location and extent of the cystogenous glands; body of specimen, 0.23 mm long.

FIGURE 3. Redia; 0.8 mm long.

FIGURE 4. Adult specimen, from a laboratory raised eider duck, ventral view, showing principal nerve trunks, ventral glandular pits, digestive and reproductive organs. The body is concave ventrally and the posterior end is curved upward, partially obscuring structures in this region; specimen 1.15 mm long.

FIGURE 5. Metacercaria, from the operculum of *Hydrobia minuta,* showing oral sucker, pigmented area, and concretions in the excretory tubules; diameter of cyst, 0.15 mm.

PLATE I



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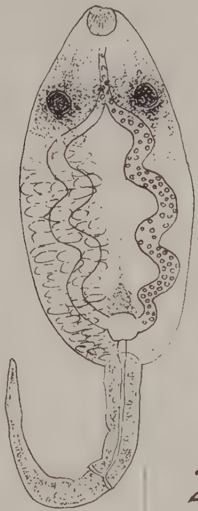

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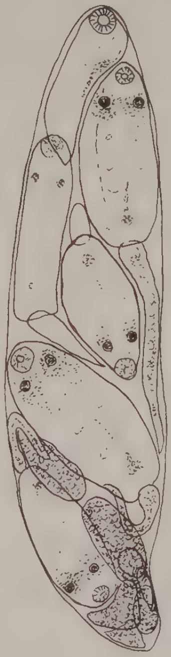

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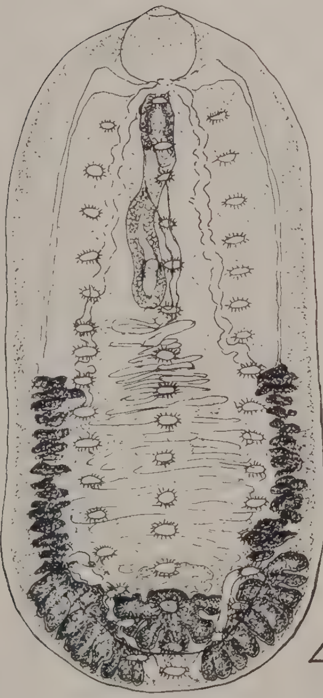

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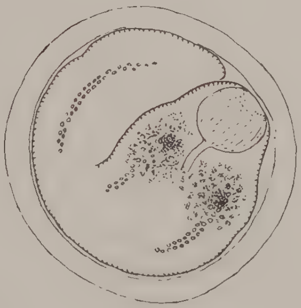

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CLYDE C. TAYLOR

TEMPERATURE, GROWTH, AND MORTALITY – THE PACIFIC COCKLE

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Temperature, Growth, and Mortality – The Pacific Cockle

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Introduction

In considering the causes of LEE's phenomenon in Georges Bank haddock, TAYLOR (1958a) suggested that a differential mortality rate associated with rate of growth could account for at least a part of the phenomenon. The concept of a relation between longevity and growth-rate is not new (e.g., PEARL, 1928; MCCAY, 1933). The idea that growth-rate may introduce a mortality rate operative over the life span appears more difficult to accept. If, however, this is true, estimations of the natural mortality rate in fish population dynamics may have been facilitated.

This paper adds yet another example of a species whose growth appears to be quantitatively related to environmental temperature and shows that longevity and natural mortality estimated from growth characteristics are in very good agreement with independent estimates obtained from the age structure of unexploited populations of the species.

WEYMOUTH and THOMPSON (1931) present growth data for the Pacific cockle, *Cardium corbis*, at 8 localities ranging from Oregon to Alaska. Treating these data in the same manner as for the Pacific razor clam (TAYLOR, 1959) but excluding lengths at ages 9 and 10 at Kake, Alaska, and at ages 1 and 11 at Snug Harbor, Alaska (because they are aberrant and based on only 1 or 2 cockles) I have calculated the growth parameters of BERTALANFFY's (1938) equation:—

$$L_t = L_\infty (1 - e^{-K(t-t_0)}) \tag{1}$$

the Bertalanffy coefficient of anabolism:—

$$E = L_\infty \times K \tag{2}$$

and an index of longevity (TAYLOR, 1958a, 1958b, 1959):—

$$A_{0\cdot95} = t_0 + \frac{2\cdot996}{K} \tag{3}$$

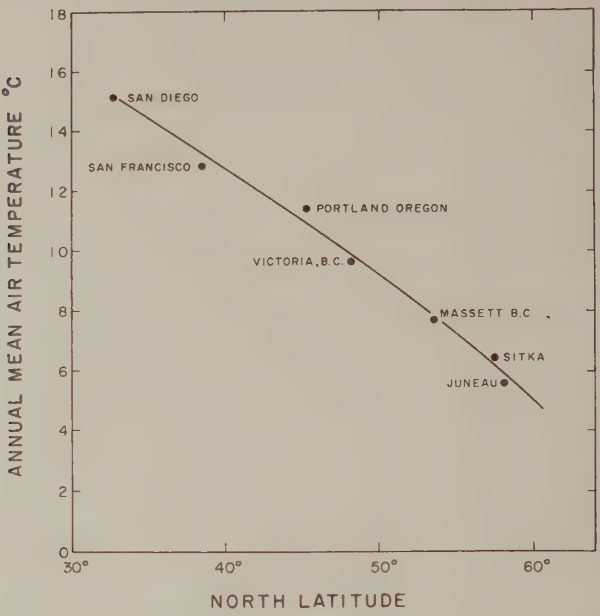

Figure 1. Smoothed curve of air temperature against latitude, San Diego, California to Juneau, Alaska.

Estimation of Air Temperatures

Figure 1 (from TAYLOR, 1959) is used to estimate the mean annual air temperatures at the localities listed in Table 1 by reading the temperature from the smoothed line which corresponds to the latitude of each locality. It is known that air temperatures along the west coast of North America are generally indicative of coastal water temperatures (ROUNSEFELL, 1930; HUBBS, 1948; KETCHEN, 1956). For the period during which WEYMOUTH and THOMPSON were collecting these data for the Pacific cockle (1920's), more air temperature information is available than inshore surface water temperatures. The close correspondence of mean annual surface water temperatures and air temperatures is shown for certain localities and periods in Table 2. These means differ somewhat from those shown in Table 1 because they are not based on the same period of years.

Relation of K to mean air temperature

Figure 2 shows the logarithms of K at the eight localities of Table 1 plotted against mean annual air temperature. The regression of log K on temperature is:

$$\log K = 0{\cdot}0632\,T - 0{\cdot}9433 \qquad (4)$$

with correlation coefficient 0·887. The 1 % level of significance for 6 degrees of freedom is 0·834 (see discussion).

Table 1

Growth parameters of *Cardium corbis*, Oregon to Alaska, and estimated mean annual air temperatures

Locality	Latitude N	Est. mean air temp. °C	K	L_∞	E	t_0	$A_{0\cdot 95}$
Tillamook, Oregon.........	45°31′	10·9	0·54	8·32	4·48	0·48	6·03
Copalis, Washington	46°58′	10·3	·62	7·70	4·76	0·52	5·35
Kake, Alaska	56°55′	6·4	·26	9·56	2·52	–	–
Cordova, Alaska...........	60°27′	4·9	·24	10·21	2·40	0·89	13·37
Constantine Harbor, Alaska.	60°35′	4·8	·26	7·67	2·01	0·80	12·32
Snug Harbor, Alaska	60°10′	5·0	·28	10·25	2·86	–	–
Kukak Bay, Alaska	58°30′	5·5	·25	11·37	2·82	·88	12·86
Port Moller	56°00′	6·8	·21	8·61	1·82	0·78	15·05

Table 2

Comparison of mean annual air and surface water temperatures at certain localities

Locality	N Lat.	Period	Mean annual temperature °C Air	Mean annual temperature °C Surface water
San Diego, Calif.	32°42′	1921–1930	16·6$^{1)}$	–
Scripps Pier, La Jolla, Calif. ...	32°52′	1921–1930	–	17·0$^{2)}$
San Francisco, Calif.	37°48′	1922–1931	13·2$^{1)}$	14·1$^{3)}$
Seattle, Wash................	44°37′	1922–1931	11·0$^{1)}$	11·0$^{3)}$

1) U.S. Weather Bureau, Climatological Data.

2) Data supplied through courtesy of Scripps Institution of Oceanography, La Jolla, California.

3) U.S. Coast and Geodetic Survey, "Surface Water Temperatures, Coast and Geodetic Survey Tide Stations, Pacific Coast." TW–2, 1945.

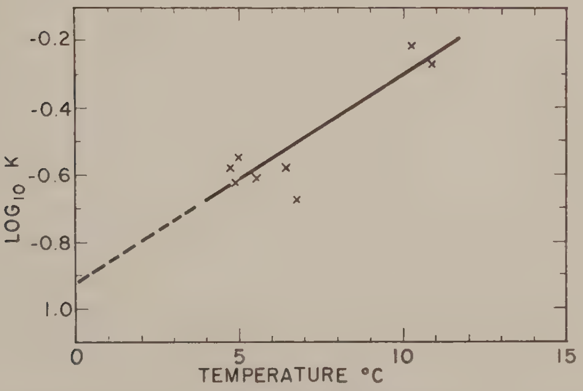

Figure 2. Regression of log K on estimated air temperature for the Pacific cockle at the eight localities shown in Table 1.

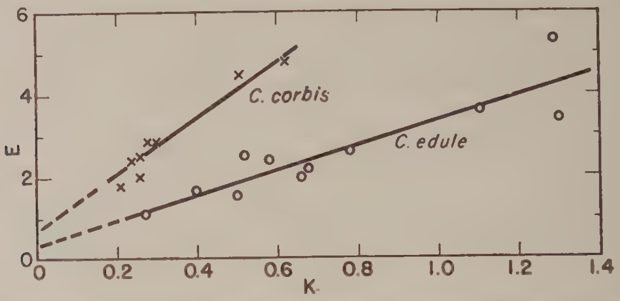

Figure 3. Regression of E on K for *Cardium corbis* compared to that for *Cardium edule*.

Relation between E and K

As with various other fish and shellfish, the relation between E and K appears linear (Figure 3) with regression equation

$$E = 6{\cdot}760\ K + 0{\cdot}715$$

Figure 3 also compares the regression of E on K for *Cardium edule* (TAYLOR, 1959), the latter being based on growth data published by COLE (1956).

Longevity

WEYMOUTH and THOMPSON (1931, Table 2) compute a "maximum age" for *Cardium corbis* for 6 of the 8 localities in Table 1. They state: "On a survival curve for each locality the age was located at which 5 percent of the clams passing through the first winter were still alive. This was taken as the maximum age." Figure 4 compares the maximum age thus computed with the $A_{0{\cdot}95}$ of Table 1.

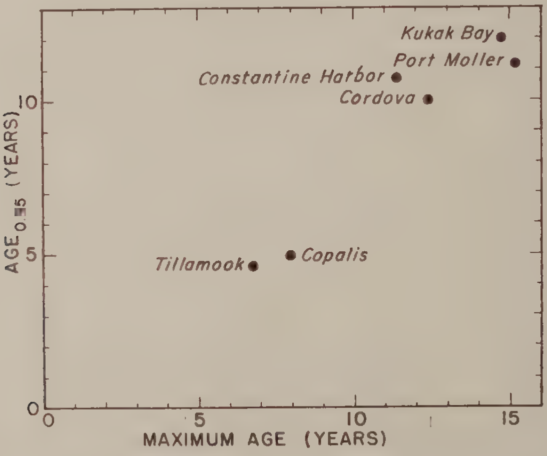

Figure 4. Comparison of maximum age estimated from age composition by WEYMOUTH and THOMPSON to $A_{0{\cdot}95}$ estimated from growth parameters.

Table 3

Estimates of the natural mortality coefficient, M, obtained from age composition data for *Cardium corbis* compared to M's estimated from $A_{0\cdot95}$

Locality	M estimated from age composition	M estimated from $A_{0\cdot95}$
Tillamook, Oregon	0·525 ±0·023	0·497 +·173 −·075
Copalis, Washington	0·594 ±0·056	0·560 +·180 −·051
Cordova, Alaska	0·286 ± ·007	0·224 +·106 −·025
Constantine Harbor, Alaska	0·384 ±0·033	0·243 +·053 −·015
Kukak Bay, Alaska	0·258 ±0·012	0·233 +·035 −·006
Port Moller, Alaska	0·225 ±0·005	0·199 +·087 −·056

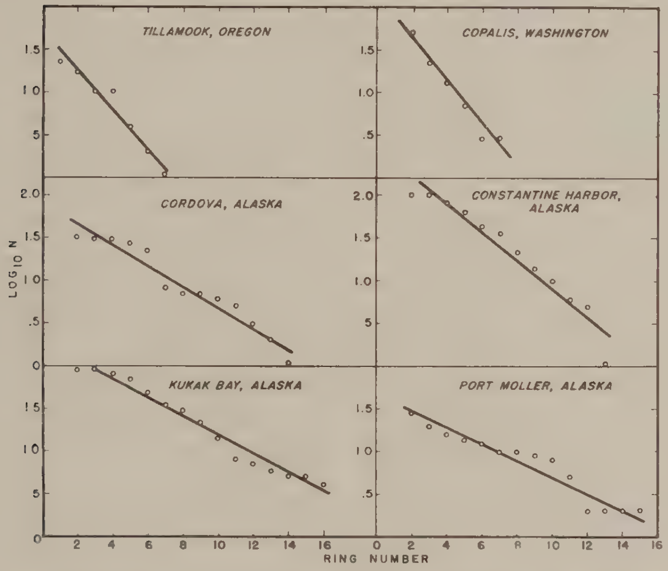

Figure 5. Regressions of the logarithm of numbers of cockles on age, as given by number of rings, at different localities.

Natural Mortality

The *Cardium corbis* populations shown in Table 1 were essentially unexploited at the time the growth data were collected. Weymouth and Thompson state (1931, p. 633): "Although the cockle is very abundant in many localities and is an excellent food mollusk, it has never attained commercial importance because of its poor keeping qualities and small edible content. The local markets absorb small quantities, and many are used by crab fishermen for bait. Attempts have been made to can the cockle, but have not met with success."

WEYMOUTH and THOMPSON consider the numerical abundance at each age (1931, Table 3) as representative of the population, with the exception of the smaller samples taken at Kake and Snug Harbor, Alaska.

Computing the regression of the logarithm of numbers on age (using ages 1–7 at Tillamook; 2–7 at Copalis; 2–14 at Cordova; 2–13 at Constantine Harbor; 2–16 at Kukak Bay; and 2–16 at Port Moller), estimates of the natural mortality coefficient, M, were obtained, together with standard errors. The goodness of fit of these regressions may be judged from Figure 5.

Alternatively, M was estimated by dividing $-\log_e(1 - p)$ by A_p, in this case 2·996 by $A_{0\cdot 95}$ (TAYLOR, 1959). Estimates of M with their standard errors are compared in Table 3.

Discussion

The slope of regression equation (4) and its associated correlation coefficient depend entirely on two values of K above 10°C (see Table 1 and Figure 1). Since the correlation surface is not normal, the probability levels are subject to question. The reader must, then, judge the validity of the relation between temperature and K in the light of similar relations found for the cod and razor clam (TAYLOR, 1958b, 1959).

Relations between growth parameters and temperature bearing as they appear to on related problems of longevity and mortality suggest certain new methods of approaching some of the thornier problems of fishery biology and population dynamics. These methods are untried, indeed unverified, but nevertheless promising.

By and large, we must assume an average response for each species to the environment and an average response for the individuals within a species. Individual variations must occur. In the haddock, for example, certain growth parameters appear associated with size at age 1, the latter sizes being more or less normally distributed (TAYLOR, 1958a, Table IV, p. 245).

On the other hand, to apply such methods, size and age data must be suitably graduated by the Bertalanffy equation, more particularly by the regression of L_{n+1} on L_1 (WALFORD, 1946). It is not at all unusual to find growth data in which the slope of the latter regression is very close to or greater than 1·0 or in which the value of t_0 is greatly in excess of $-$ 1·0. In such instances, one must conclude either that the animal does not grow in a manner described by the Bertalanffy equation or that the growth data themselves are in error. The effect of an error in estimating the time at which the first annulus in hard parts is formed on the value of t_0 may be readily seen by treating the size at age 2 as if it were age 1 and so on.

Air temperatures, especially when estimated from latitude, are at best crude measures of environmental temperature. The air temperature at Port Moller, Alaska (Table 1), for example, is probably lower than the latitude of the location would indicate since Port Moller lies on the northern side of the Alaskan Peninsula on the Bering Sea.

The regression of log K on temperature for the three species, cod, razor clam, and Pacific cockle are as follows:—

Cod	$\log K = 0{\cdot}0768\, T - 1{\cdot}4380$
Razor clam	$\log K = 0{\cdot}0849\, T - 1{\cdot}0987$
Pacific cockle	$\log K = 0{\cdot}0632\, T - 0{\cdot}9433$

The slopes of these regressions do not differ significantly. They are, however, approximately three times as great as, and differ significantly from, what we would expect for a Q_{10} of 2 or 3, say. (Q_{10} is the ratio of the rate of activity at one temperature to the rate at a temperature 10°C lower.)

A temperature-determined K, linearly related to E, determines the maximum size, L_∞. One may ask what happens to an animal at or near L_∞ if the average environmental temperature increases or decreases by one or more degrees centigrade?

If the temperature increases, K increases, $A_{0 \cdot 95}$ decreases, and the animal finds itself larger than the L_∞ defined by the conditions of the new environment. In terms of the concepts behind the Bertalanffy growth equation, the animal has attained a body volume now larger than the functional surface area can support.

One readily sees from equation (1) that a temperature change at any time amounts to a displacement of all animals from the growth curve defined by the temperature conditions of the former environment. Assuming that there cannot be negative growth, that t_0 is fixed during the first year of life and that the temperature change defines a new K and a new L_∞, the only remaining parameter which can be changed to make the equation balance is t. A change in t to satisfy the equation can only be interpreted as a change in the physiological age of the animal. Thus, displacements from the growth curve brought about by temperature changes must be regarded as having changed the physiological age of the animal with reference to its environment.

Calculations readily show that such "time" displacements are relatively slight for the younger and smaller animals over a wide range of temperatures, perhaps explaining the commonly-observed resilience of young animals to extremes of temperature. For animals at or near L_∞ changes amounting to only fractional degrees centigrade result in large "time" displacements. At intermediate sizes, the displacement depends on the amount of temperature change.

These results suggest a "trigger mechanism" for mass mortalities of animals. Extensive mortalities brought about among the larger animals by relatively slight temperature changes may introduce secondary bacterial or fungus diseases which extend to all sizes in the population. This hypothesis would explain many of the puzzling aspects of mass mortalities, especially those where a "causative" organism does not always cause mortality by its mere presence. The possibility that the herring fungus disease, *Ichthyosporidium hoferi* becomes widespread in 18-year cycles (FISH, 1934) even though the fungus is always present in herring populations (SCATTERGOOD, 1948) is suggestive in this respect.

Summary

Growth parameters of the Pacific cockle, *Cardium corbis*, are shown to be quantitatively associated to mean air temperatures. Values of E and K follow a linear trend different from that of *Cardium edule*. Longevity, estimated as $A_{0 \cdot 95}$, is in proportion to the maximum age as estimated by WEYMOUTH and THOMPSON. Estimates of natural mortality from the parameter $A_{0 \cdot 95}$ are in very good agreement with similar estimates based on the observed age compositions of unexploited populations of the cockle.

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The Bottom Fauna of Lake Huron[1]

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ABSTRACT

The examination of 63 bottom samples, collected in Lake Huron in 1952 and 1956, revealed that *Pontoporeia affinis* was the dominant organism in both deep and shallow water. The next most abundant organisms in deep water were oligochaetes, fingernail clams, and midge larvae. Midge larvae were more numerous than either oligochaetes or fingernail clams in shallow water. The number of organisms per square meter was similar to that determined from a similar study on Lake Michigan.

INTRODUCTION

Very little has been published on the bottom fauna of the Great Lakes. A number of qualitative studies or ones limited to specific groups have been published, but only three quantitative studies of open-lake conditions have appeared (Lake Erie—Shelford and Boesel, 1942; Wright, 1955; Lake Michigan—Eggleton, 1936, 1937). In each lake a single dominant organism outnumbered all others combined. In Lake Erie it was the larva of the mayfly *Hexagenia*. In Lake Michigan it was the amphipod *Pontoporeia*.

The present paper reports on 63 samples taken from 28 stations in Lake Huron (Figure 1) by the U. S. Bureau of Commercial Fisheries research vessel *Cisco* in 1952 and 1956. Although the samples are few for so large an area, the results agree well with Eggleton's from Lake Michigan.

METHODS AND EQUIPMENT

Twenty-five single samples were taken during September and early October 1952 (stations 198-230, Figure 1). Sampling depths ranged from 5.5 to 119 meters. Temperatures ranged from 4.2° C. to 7.1° C. in the deep-water samples (greater than 25 meters) and from 13.7° C. to 19.7°C. in the shallow-water samples (5.5 to 25 meters).

The other 38 samples were taken in 1956. One was a single sample (station 65) taken off Harbor Beach, Michigan, at a depth of 46 meters—temperature 4.9° C. The rest were multiple samples taken from stations 62 and 64 at intervals throughout the season from June 21 to October 27. Station 62, 33 meters deep, was in the mouth of Saginaw Bay. Bottom temperatures varied between 5.7° C. and 11.4° C. Station 64, also 33 meters deep, was off the east shore of the "thumb" of Michigan. Bottom temperatures ranged between 4.9° C. and 12.2° C. The bottom at both stations was mainly sand; some samples contained a little mud and others a little gravel.

All samples were taken with a Petersen dredge having a cross-section area of 737 square centimeters. The mud and fine sand were rinsed off through a screen of U. S. Sieve Series, No. 30 mesh. The organisms were recovered manually or floated out of the remaining sand in a saturated sucrose solution (specific gravity of 1.110) and preserved, one sample to a bottle, in 70 percent alcohol. The contents of each bottle were examined under binocular microscope and the individuals of each species counted. Results from the 2 years are not separated, since 1952 stations were not revisited in 1956. Consequently, there is no basis for an annual comparison.

LIST OF ORGANISMS

Organisms from 15 major taxonomic groups were present in the samples. Those marked with asterisks were found only in the 5.5- to 25-meter depth zone; others occurred at depths between 5.5 and 119 meters.

Hydra
Turbellaria—at least two species
Nematoda—at least two species
Oligochaeta
    Naidium sp.
    Limnodrilus claparedianus

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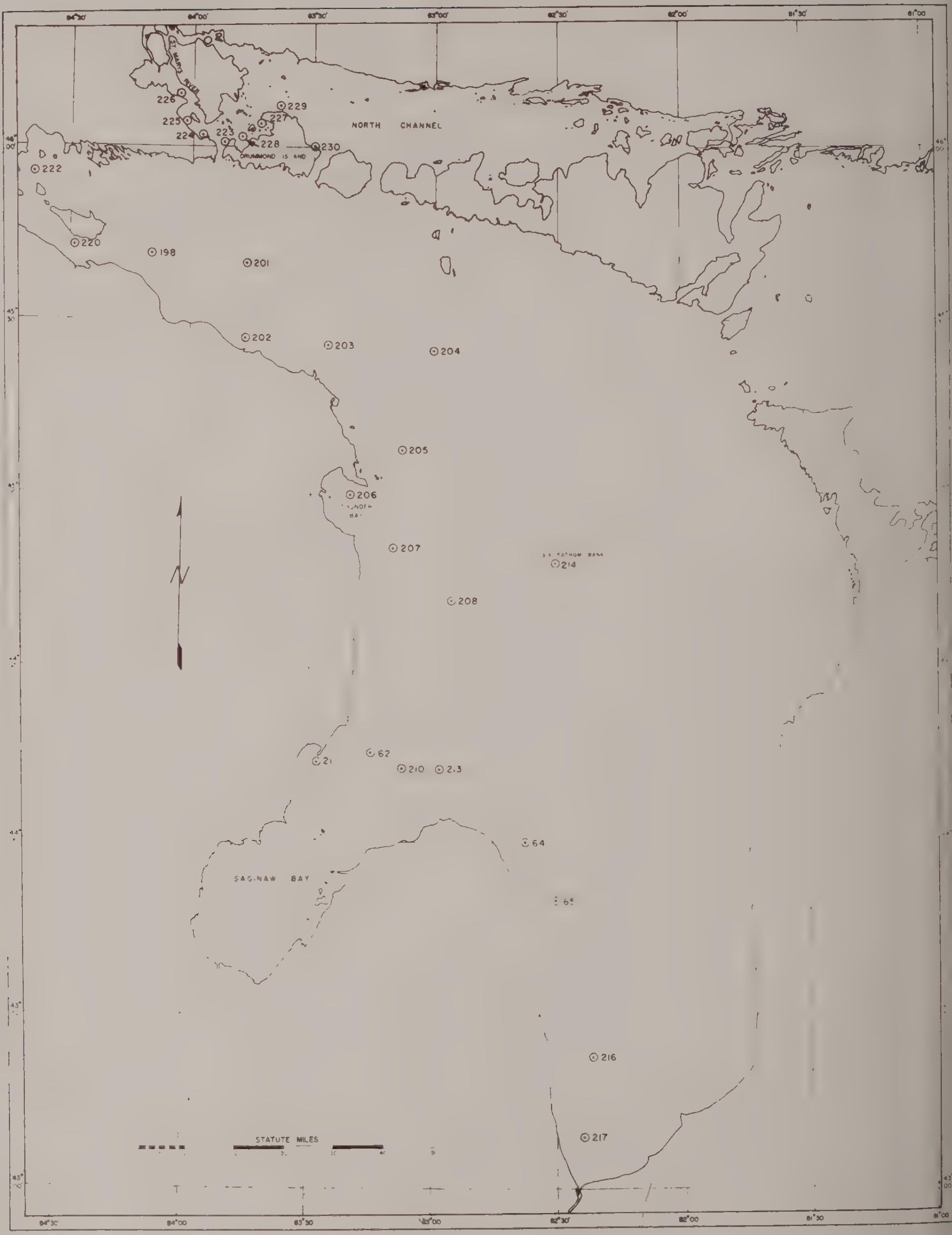
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NORTH CHANNEL
DRUMMOND ISLAND
222
220
198
201
202
203
204
205
206
THUNDER BAY
207
SIX FATHOM BANK
214
208
N
211
62
210
213
64
SAGINAW BAY
65
216
217
STATUTE MILES

Figure 1.—Lake Huron showing principal stations.

- Hirudinea
  - *Glossiphonia**
  - One unidentified
- Pelecypoda
  - *Pisidium*
  - *Sphaerium*
- Gastropoda
  - *Lymnaea**
  - *Valvata*
- Ostracoda
  - *Darwinula stevensoni*
  - One unidentified
- Isopoda
  - *Asellus* sp.
  - *Lirceus* sp.*
- Amphipoda
  - *Gammarus* sp.*
  - *Pontoporeia affinis*
- Mysidacea
  - *Mysis relicta*
- Ephemeroptera
  - *Hexagenia* larvae*
- Trichoptera larvae
  - *Molanna* sp.*
  - *Polycentropus* sp.*
  - Unidentified—at least two species*
- Megaloptera
  - *Sialis* sp. larvae*
- Diptera (Tendipedidae—one or more species of the following genera)
  - *Tendipes**
  - *Glyptotendipes**
  - *Clinotanypus*
  - *Calopsectra*
  - *Procladius*
  - *Spaniotoma*
  - *Cryptochironomus**
  - *Polypedilum*
  - Several unidentified

DISTRIBUTION AND ABUNDANCE OF DOMINANT ORGANISMS

Pontoporeia affinis was the dominant organism (Table 1). This amphipod constituted 81 percent of all specimens in the deep-water samples. It also occurred in reduced numbers in the shallower waters of the St. Marys River and the North Channel. It did not occur in areas of the same depth in Saginaw Bay[3] (not covered in this study). Wright (1955) did not find *Pontoporeia* in similar depths in western Lake Erie. It is possible that temperature rather than depth limits its distribution. Temperature records collected by the U. S. Bureau of Commercial Fisheries indicate that, although shallow, the water in the St. Marys River and North Channel is cooler than in Saginaw Bay. The extensive shallows of Saginaw Bay and western Lake Erie warm to rather high temperatures in summer.

Pontoporeia was carrying eggs in only one sample (station 65, August 3, 1956). In other samples it was possible to recognize a group of very small individuals of uniform size. They constituted 57 percent of all *Pontoporeia* in samples from station 64. At this station they were about 2 millimeters long in June and about 3 millimeters in October. The rest of the *Pontoporeia* were of various sizes, but all were distinctly larger than the numerous small individuals. In midsummer the volume of these larger *Pontoporeia* averaged about 10 times that of the small ones. Evidently *Pontoporeia* usually breeds once a year in Lake Huron and grows slowly. The major breeding season probably is in winter or early spring.

Oligochætes and fingernail clams, *Pisidium*, were next most abundant (Table 1). Only three of the 63 samples did not contain oligochætes.

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[3] Unpublished records from a cooperative study of Saginaw Bay by the Bureau of Commercial Fisheries and the Michigan Department of Conservation.

TABLE 1.—*Average number of organisms per square meter in Lake Huron bottom samples, 1952 and 1956*

[Shallow-water stations were in depths of 5.5 to 25 meters inclusive; deep-water stations in depths of 25 to 119 meters.]

Group of stations	Number of stations	Number of samples	*Pontoporeia affinis*	*Pisidium*	*Limnodrilus claparedianus*	*Naidium* sp.	Midge larvae (*Tendipedidae*)	Midge pupae	Nematodes	All other organisms	All organisms
All stations	28	63	1,119	129	121	7	36	9	4	36	1,461
Shallow-water stations	11	11	334	65	35	6	77	23	4	81	625
All deep-water stations	17	52	1,627	170	176	7	9	0.5	6	7	2,002
Deep-water stations except 62 and 64	15	15	1,343	161	115	4	7	0	4	6	1,640
Station 62	1	11	2,018	35	398	1	16	4	2	7	2,481
Station 64	1	26	5,495	444	868	63	32	4	46	14	6,966

Pisidium was in all samples except eight. Numbers of these two groups were about equal. Cocoons of the worms were common throughout the summer, although relatively few newly-hatched worms were collected. They were probably lost in the original sorting. The counts of worms are little better than estimates, since the specimens usually were broken, sometimes into several pieces.

No attempt was made to separate *Pisidium* into species. Oligochætes, however, were identified by Eugene W. Surber who determined that there were but two species. The more numerous was *Limnodrilus claparedianus* Ratzel. The less abundant worm was a member of the genus *Naidium*, probably a new species. The fact that it has missed the attention of the taxonomists until now, even though it exists by the millions in Lake Huron and probably in the other Great Lakes, emphasizes how little work has been done in these important bodies of water.

Nematodes occurred in 26 samples (Table 1). Of course there may have been numerous microscopic nematodes which went through the washing screen.

The only insects taken in deep water were midge larvæ (Tendipedidæ), which occurred in about two-thirds of all samples. The number of individuals was generally small (Table 1), but the number of species was large. Eight genera were identified. Some of these probably included more than one species. Over 30 percent of all midge larvæ remain unidentified. An extensive study of this group might show species preferences for certain depths, temperatures, dissolved-oxygen concentrations, bottom types, or distances from shore. *Spaniotoma* and an unidentified midge were the only ones abundant in deep water. *Tendipes*, *Glyptotendipes*, and *Cryptochironomus* were taken only in shallow water.

Fewer than one-third of the deep-water samples contained any organisms other than in the above-mentioned five groups. Among those collected were partially pelagic forms *(Mysis relicta* and ostracods) caught by chance in the dredge. The shallow-water samples contained more types. Small fragile specimens were undoubtedly lost in sorting the organisms from the sediments. Statoblasts were found in some samples but not a single bryozoan. *Hydra* occurred in one sample from station 64.

One very curious sample (227), taken from 5.5 meters off the west shore of Drummond Island, contained the isopod, *Lirceus*, the mayfly, *Hexagenia*, and midge larvæ instead of the usual *Pontoporeia*, oligochætes, and *Pisidium*. The estimated numbers per square meter were: 535 isopods, 108 midge larvæ, and 68 *Hexagenia*. A few caddis-fly *(Molanna, Polycentropus)* and alderfly *(Sialis)* larvæ were taken.

COMPARISON WITH BOTTOM FAUNA OF LAKES MICHIGAN AND ERIE

The average number of animals per square meter for all stations of 1952 and 1956 was 1,461 (Table 1). If data from the two more productive stations (62 and 64) are not included in calculation of the average, then the figure is 1,211 per square meter. This value approximates the average number of organisms per square meter in Lake Michigan. The means of the monthly averages presented by Eggleton (1937) give values of 1,242 and 1,150 animals per square meter for 1931 and 1932, respectively.

The high productivity at stations 62 and 64 may be the result of flow of the rich waters of Saginaw Bay into the vicinity of these stations (Beeton, 1958). Station 64 was unusually productive (Table 1). The only other station approaching the productivity of stations 62 and 64 was 214 near the Six Fathom Bank. The greatest concentration of organisms was in one sample taken at station 64 on October 5, 1956. It contained 10,556 organisms per square meter. Eggleton (1937) reported a maximum of 11,440 animals per square meter.

The number of animals per square meter in the deep water (25-119 meters) of Lake Huron, excluding stations 62 and 64, was 1,640 (Table 1). The number of organisms per square meter in the combined 1931-32 Lake Michigan samples from 20-119 meters was 1,635 (this figure is the mean for this depth interval—Eggleton, 1937).

The organisms per square meter were fewer in the shallow-water samples—average 625 (Table 1). This figure approximates the average of 587 animals per square meter in the shallow west end of Lake Erie in 1930 (Wright, 1955—figure is the average of the means for various organisms). The shallow waters of Lake Huron, however, were undoubtedly much less productive than those of Lake Erie in terms of biomass, since large organisms, especially *Hexagenia*, were more plentiful in the Lake Erie samples.

Seasonal changes in the abundance of organisms, such as noted by Eggleton (1937) in Lake Michigan, were not observed at station 64, although sampling was conducted once or twice a month from June through October.

ACKNOWLEDGMENTS

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Thanks to pet foods, Gulf Coast fishery catches have changed

From Trash to Treasure

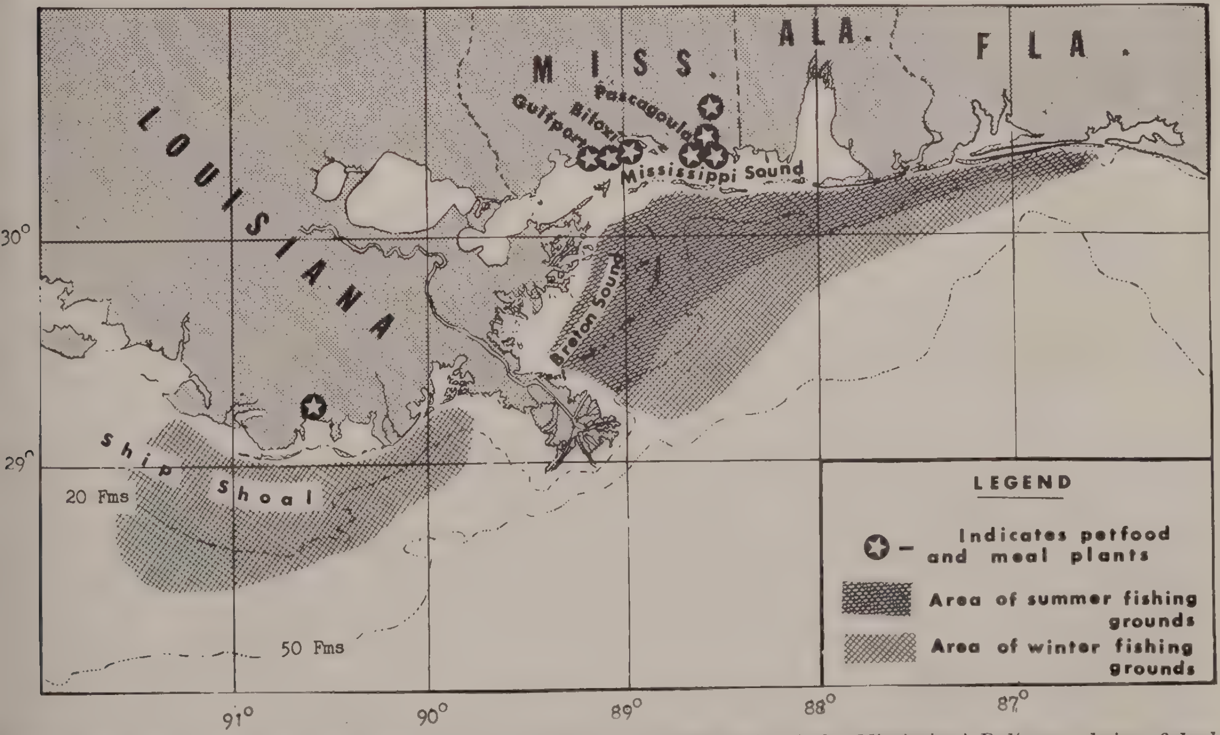
THIS ARTICLE describes the pet food fishery of the north-central Gulf of Mexico. Herein are related the "whats, whys and hows" of the rise of a fishery, initiated only eight years ago, to the point where it utilized most of the industrial fish landed in the region in 1959, exclusive of menhaden, and changed the designation of a fishery resource from "trash" to "valuable raw material."—THE EDITOR.

by J. R. THOMPSON
and W. A. HASKELL
U. S. Bureau of Commercial Fisheries, Pascagoula, Miss.

CONTIGUOUS to the coasts of the Gulf States, and receiving a rich nutrient supply from the Mississippi River, are hundreds of square miles of relatively shallow water underlain by muddy bottoms. These long have been the site of a profitable and famous shrimp fishery.

For over 40 years these fishermen have been dragging their trawl nets over the bottoms. In addition to the highly sought shrimp, their trawls have scooped in quantities of fish that, because of the large number of species represented in the catches and the small average size of the individuals, were unmarketable prior to 1952.

These fish were considered a nuisance by the shrimp fishermen, were termed "trash" and were discarded. So numerous were the fish in some parts of the shrimping grounds that they seriously interfered with shrimp-


ALA.
FLA.
MISS.
LOUISIANA
Pascagoula
Biloxi
Gulfport
Mississippi Sound
Breton Sound
Ship Shoal
20 Fms
50 Fms
30°
29°
91°
90°
89°
88°
87°
LEGEND
Indicates petfood and meal plants
Area of summer fishing grounds
Area of winter fishing grounds

Site of the Gulf Coast pet food fishery. Rich grounds on either side of the Mississippi Delta are being fished to provide raw material for the production of food for the nation's estimated 26 million pet cats. Original production was centered in the waters immediately adjacent to Pascagoula (upper center). From there, the fast-growing fleet has fanned out so that it now covers the area contiguous to the states of Louisiana, Mississippi and Alabama as well as portions of the coasts of Texas and Florida in waters ranging in depth from 3 to 30 fathoms (18 to 180 feet).

ing activities, and these localities of high fish concentration, once noted. were avoided by the shrimp fleets.

Pet Foods to the Rescue

Concerned about the yearly wastage of tons of fish—caused not only by the practice of discarding fish from the shrimp trawl catches, but also by the nonutilization of an extensive natural resource — the Gulf Coast people cast about for markets for the nonutilized fish. They found one such market in the industrial utilization of trawl fish by the pet food industry. As a result, today the grounds once trawled on a commercial basis exclusively for shrimp are also the site of an extensive commercial trawl-fish fishery.

Examination of the catches of the pet food trawlers has been carried out by biologists of the U. S. Bureau of Commercial Fisheries in an attempt to understand more fully the biological nature of the resource. These studies, although far from complete, have indicated that, year in and year out, approximately 76% of the average trawl catch consists of small croakers, spot, and white sea trout.

Industrial Utilization Surpasses Food Use

IN 1959, for the first time in the history of this country's fisheries, over one-half of all fish landed by commercial vessels were destined for so-called "industrial utilization"—processing into meals, fish flours, oils, solubles and pet foods. The pet food industry has played an important role in this increased industrial utilization, and this industry and its fisheries have become interconnected to the apparent advantage of both.

Does Not Harm Sport Fishing

These fish, even when fully mature, are of small size in Gulf waters and are not considered suitable for direct human consumption or for sport fishing purposes.

The remaining 24% of the average catch includes, seasonally, some 150 species, but those fish normally thought of as food fish or sport fish are generally absent, even from this smaller percentage. The trawl is a selective gear and is not suited to the capture of the fast-swimming, highly maneuverable food fish and sport fish of the region.

Pet food plants originally sought to utilize the fish caught incidental to shrimping operations by using the shrimp fleet as a direct source of supply. But this plan, although theoretically sound, was subject to serious practical drawbacks: Fishermen continued to concentrate on areas where clean catches of shrimp could be obtained, and they avoided areas of high fish concentration; the supply of fish was not only limited in extent, but was extremely erratic and difficult to control, and the fish, usually being left on deck until after the shrimp were cared for, were often of poor quality when landed.

Turn to Their Own Fleets

As a result, the pet food plants turned to the utilization of fleets of vessels fishing exclusively for pet food fish. The vessels of the first pet food fleets were mainly old shrimp boats of small size and limited range, capacity and seaworthiness. These boats were forced to fish close to the plant and production was controlled by the vagaries of the weather.

Gradually, however, the original vessels became unserviceable or unable to compete, and they were replaced by newer and more efficient vessels. Today the fleets contain some of the most mod-

Vessels of the pet food plant at the dock. A wide variety of vessel types is represented in the present fleet, but most vessels are of either "Biloxi" or "Florida" design. "Biloxi" boats are characterized by a stern-placed deckhouse, whereas "Florida" trawlers are built with the deckhouse placed forward of the midline. The average vessel in the pet food fleet today was built originally for the shrimp fishery, measures approximately 50 feet in length, is capable of carrying between 20 and 40 tons of fish, and is 12 years of age. All pet food trawlers are diesel powered.

ern vessels of the coastal fisheries of the Gulf.

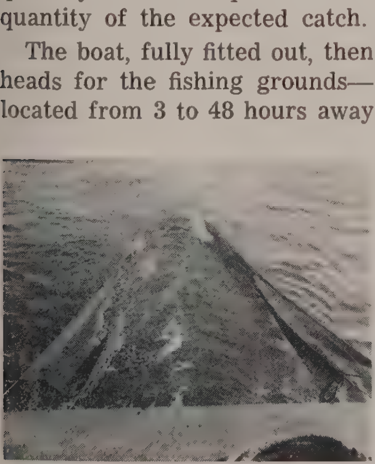
The vessels are operated on rigidly controlled schedules, designed to provide for a relatively level and continuous supply of fish, and the catch landed is subjected to rigid standards to assure quality. This system of regulated operation has worked out to the apparent satisfaction of both plants and vessel owners.

Fishery Methods and Equipment

The methods and equipment utilized by pet food fishermen can be explained best by following the course of events aboard a trawler from the time it leaves the dock to the time that the catch is landed.

Once the boat has been fueled, and groceries and miscellaneous supplies sufficient for an average trip of three to five days have come aboard, it moves to the ice dock. Here 300-pound cakes of ice are run through a crusher, and the resultant pebble-sized pieces are blown into the hold of the vessel through a flexible metal hose. In summer months, warm water and air temperature often make necessary an initial quantity of ice equal to the quantity of the expected catch.

The boat, fully fitted out, then heads for the fishing grounds—located from 3 to 48 hours away—at average vessel speeds of 8 to 10 knots. En route, the crew makes last-minute adjustments to the gear and listens attentively to reports of fishing conditions coming over the radio-telephone receiver from other trawlers on the grounds.



Setting the trawl from a "Biloxi-type" trawler. Wires from the forward corners of the net lead to "doors" or trawl boards which are towed at an angle and serve to hold the mouth of the net open. Wires from the trawl boards lead to the winch aboard the vessel.

Established in 1952, this large pet food plant at Pascagoula, Miss., was the original processing plant for trawl-caught "industrial fishes." It has undergone extensive modernization several times since.

Once the grounds are reached, the first trawl drag commences. The trawl net, which has been laid out on the deck, preparatory to setting, is put over. Then, as the vessel moves ahead, the winch is freed, and the required amount of wire "warp" is let out so that the trawl will reach and fish on the bottom.

The trawl is dragged slowly over the bottom for a period varying from 30 minutes to three hours. Then the trawl warp is wound in on the winch until the trawl doors are on board. With the vessel slowly circling to keep the floating net away from the propeller, the terminal portion of the trawl is hoisted aboard and suspended from the boom. By pulling the ends of a line fastened about the end of the trawl bag, the catch, which may consist of as much as five or six tons of fish, is dumped either directly into the hold or on deck.

In the latter case, the catch is sorted roughly, salable food fish and shrimp are stored sep-

Plan International Conference

The U. S. Bureau of Commercial Fisheries is assisting the Food and Agriculture Organization of the United Nations in planning an international conference on fish in animal and human nutrition to be held in Washington, D. C.

While this conference does not take place until September, 1961, the U. S. Bureau proposes the early establishment of regional industry consultation groups. These will be kept informed of all planning and progress. The groups will be asked to make suggestions and recommendations relating to the conference and to preconference planning. It is expected that the regional group members will, in turn, acquaint other regional processors and fishermen with the objectives and progress in planning the sessions.

Members of the pet food industry who have a special interest in fish ingredients may be interested in participating in the regional consultation meetings. If so, it is suggested they write to the U. S. Department of Interior, Bureau of Commercial Fisheries.

arately, and extraneous matter discarded. The remaining catch is then shoveled into the hold and iced down. Where the catch is dumped directly into the hold, sorting is accomplished later at the plant. The trawling procedure continues night and day until the hold is full, supplies run out, or the fish can no longer be kept without danger of quality loss, at which time the trip home commences.

Process Within the Plant

At the smaller plants, fish are shoveled from the hold of the vessel into a hopper and are then moved into the plant on a conveyor. At the larger plants, a suction pump connected to a flexible metal hose is used to remove the fish quickly and with little effort. The fish then pass along a conveyor in the plant where women sort the catch. All food fish and shrimp are removed, given back to the vessel operator, and sold on the seafood market. Extraneous matter, including dead shell, crabs, excessively spiny fish and seaweed, is also removed. The remaining fish continue along the conveyor line, are processed, and otherwise readied for market.

Expenses of the trawler—fuel, groceries, ice—are paid from the money received from the sale of the fish, and the balance is split into "shares." As a rule, the captain receives from 1 to 1½ shares, crew members one share each, and a final share is laid aside for the boat—to cover expenses of normal maintenance and repair. If the owner is not the operator, a further one-half to one share is usually allotted to the owner. Following this system, pet food fishermen can expect to earn, generally, from $3,000 to $5,200 a year.

Contrasted with most other fisheries of the Gulf, the pet food fishery occupies an advantageous position. Trips are regulated and relatively equal in duration; the fishery extends throughout the year rather than only seasonally; the grounds utilized are approximately the same the year-around, unlike the grounds of the shrimp fishery which change from season to season, and, in aggregate, include the entire rim of the Gulf. The fisherman is assured a market and a relatively unvarying price for his catch. To date, there has been little difficulty in finding men and vessels to supply the fish.

Recently, several vessels of the fleet have installed refrigeration systems. With this means of preserving the catch, with the increased capacity and range of the vessels now entering the fleet, and with a continuation of the current tendency of the industrial fish industry of the Gulf Coast to expand its production, pet food fishing in the future undoubtedly will be conducted over extensive additional areas — in waters both deeper and more distant than those now fished. Explorations by the M/V Oregon, research ship of the U. S. Bureau of Commercial Fisheries, have disclosed additional nonutilized fish resources in deeper waters that may well surpass the shallow-water resources in terms of available fish.

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Directional Fish Counter for Field Use

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(Received August 4, 1959; and in final form, December 14, 1959)

A NEW instrument, using two conductivity-bridge detectors and a four-relay logic network, which indicates upstream and downstream passages separately, and which ignores incomplete passages, fish below a predetermined size, and most debris, has been developed and proven in the field.

Lethlean[1] has described a one-tunnel fixed-station directional fish counter that utilizes a conductivity bridge and a phase-sensitive detector energized at power frequency, followed by a time-sensitive relay system for tallying individual fish passages by direction. We have found that (1) a two-tunnel system employing two separately excited conductivity bridges, each self-balanced for changes in conductivity of the water, and (2) a simple four-relay logic network, together give a directional count that is independent of fish velocity and behavior in the tunnel; the equipment is portable and economical.[2]

Both methods utilize the difference between the specific resistance of fish and fresh water. For instance, trout and salmon measure between 380 and 780 ohm cm,[1,3,4] and fresh water in the Pacific Northwest may fall anywhere between 1200 and 65 000 ohm cm, depending upon location and season.

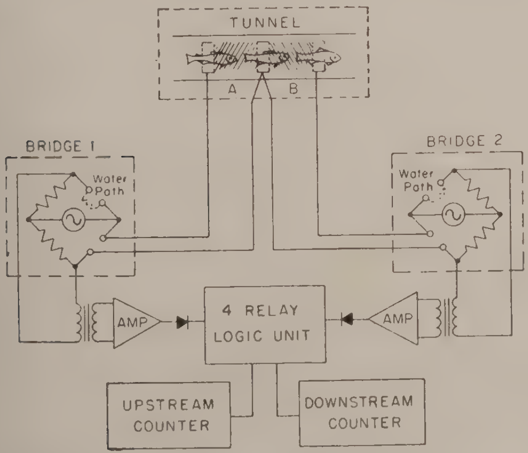

FIG. 1. Directional fish counter for field use. Water paths shown as dotted bridge legs are usually in second identical tunnel.

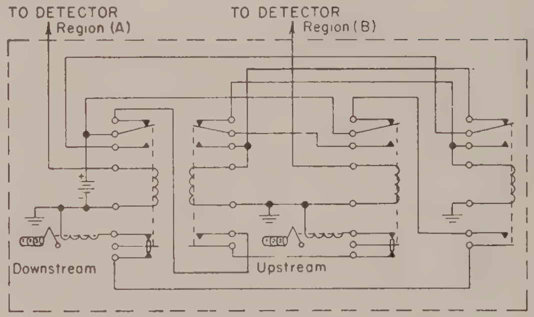

FIG. 2. Relay logic unit for directional counting. Make-before-break contacts supply appropriate impulse counter with actuating current as fish leaves tunnel.

A fish entering the tunnel unbalances the first, second, both, or neither of the conductivity bridges. Any single complete registered passage by a fish through a tunnel must include the following sequence or its inverse through the regions A and B (Fig. 1): (1) not A, not B; (2) A, not B; (3) A and B; (4) not A, B; and (5) not A, not B. Sequences are analyzed by the relay network (Fig. 2) to provide outputs into upstream and downstream registers only when complete passages have occurred; directional symmetry results in economy of logic elements. False starts or holding up in a tunnel cause no error in the count in either direction.

Tunnels are fabricated[5] of a nonconducting reinforced polymer. The transistor circuitry[6] of the audio oscillator and null amplifier are submerged in a metal tube to provide a shielded environment at an adequately constant temperature. No vacuum tubes are used. Power supply, plug-in logic unit, and counters are contained in a register unit usually enclosed on shore. Power may be supplied by dry or wet batteries or by an ac line.

Manual balancing of the two bridges, sometimes necessitated by asymmetries in tunnel and electrode geometry, is accomplished by potentiometers located in balance units. The minimum size of fish to be counted can be controlled within given limits by the adjustment of the detection threshold, as well as by the initial design of electrode shape and spacing.

Generally, if runs of fish are heavy and orifices are large enough to provide free passage, more than one fish may pass at the same time. The ratio of verified visual count to electric counts provides a statistical correction factor which, when applied to the register count, has given high accuracy at certain sites. Generally, for highest accuracy, the smallest acceptable tunnel is used. Where more than 100 fish pass in a given hour, one tunnel is placed out of the line of migration to avoid simultaneous occupancy of two tunnels.

A nondirectional counting system similar to one described earlier[7] can be assembled from a detector, a balance unit, a register unit, and simpler tunnels.

[1] N. G. Lethlean, Trans. Roy. Soc. Edinburgh, 62, Part II 479 (1953).

[2] R. H. vanHaagen, "Bi-directional electric counting system," U. S. Patent No. 2 893 633 (1959), 6 pp.

[3] Roy E. Nakatani, "The average specific electrical resistance of some salmonids." University of Washington, School of Fisheries, Technical Rept. No. 4., 1 (1955).

[4] D. E. Engstrom and G. E. Monan, personal communication, 1960.

[5] George M. Lucich, "Specifications for ten inch diameter fish counting tunnel" (unpublished).

[6] Telemetering Corporation of America, Sepulveda, California.

[7] R. H. vanHaagen, J. Audio Eng. Soc. 4, 151 (1956).

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A NOTE ON A STABILIZED STARCH INDICATOR FOR USE IN IODOMETRIC AND IODIMETRIC DETERMINATIONS

The problem of preventing biotic hydrolysis of aqueous starch indicators has stimulated innumerable searches for preservatives capable of sustained anti-biotic effect. Walton (1928) has listed abstracts of twenty-three methods purporting to prevent hydrolysis for periods ranging from two months to three years. A more recent and widely-used method is that of Hillebrand and Lundell described by Pierce and Haenisch (1948 p. 237). The method uses 1 g of boric acid per 100 ml of indicator solution.

At this laboratory we have tried several of the recommended methods with varying degrees of success and obtained the most favorable results with a modification of the method described by Hillebrand and Lundell (Pierce and Haenisch 1948). We have increased the starch concentration to 5% and have protected the stock bottle and the dispensing bottle from light. Under these conditions, hydrolysis was inhibited in the stock bottle for periods ranging from one to six months. However, in the dispensing bottle in which the contents were repeatedly exposed to the atmosphere, deterioration was rapid and the supply had to be frequently replaced.

The reliability of such solutions is not satisfactory where mass production techniques are required. In addition we have one or more isolated insular stations where iodometric work is being performed by persons without chemical training and using limited facilities. Our goal then, has been to find a starch indicator simple to prepare, economical to use, and free from hydrolytic deterioration for at least a year and preferably longer.

Experience with different methods of preserving aqueous suspensions indicated that the most satisfactory way to obtain the stability we desired was to work with a nonaqueous medium, which in itself is an unfavorable ecological medium, rather than to rely on toxic additives to suppress biotic activity in a highly favorable growth medium. A modified starch glycerite was considered. Referring to Walton (1928) again, we find that he catalogued eight abstracts covering the reactions of heated glycerine and starch. In these and subsequent publications there is a great diversity of opinion (frequently conflicting) as to the reaction(s) involved and the nature of the product(s) of such reactions. The following résumé concerning the formation of soluble starch illustrates the ambiguities in the literature:

A) Walton (1928 p. 11)

$$\text{Starch heat} \xrightarrow[\text{glycerin}]{} \frac{\text{soluble starch}}{\text{(blue iodine reac.)}} \longrightarrow \frac{\text{hexa saccharide}}{\text{(red iod. reac.)}} \longrightarrow \frac{\text{Trisaccharide}}{\text{(no iod. reac.)}}$$

B) Grant (1944 p. 802)

$$\text{Starch heat} \xrightarrow[\text{glycerin}]{} \frac{\text{Sol starch (amylodextrin)}}{\text{(yellow iod. reac.)}}$$

C) Ibid.

$$\text{Starch heat} \xrightarrow[\text{glycerin}]{} \text{Starch glycerite}$$

D) Bernthsen (1941 p. 372)

1. $$\text{Starch cold, dil} \xrightarrow[\text{acid}]{} \text{soluble starch}$$
2. $$\text{Starch heat} \xrightarrow[\text{glycerin}]{} \text{soluble starch}$$
3. $$\text{Starch hydrolysis} \xrightarrow{} \frac{\text{amylodextrin}}{\text{(blue iod. reac.)}} \longrightarrow \frac{\text{erythrodextrin}}{\text{(red iod. reac.)}} \longrightarrow \frac{\text{achroodextrin}}{\text{(no iod. reac.)}}$$

E) Gregory (1942 p. 602)

$$\text{Starch heat} \xrightarrow[\text{glycerin}]{} \frac{\text{soluble starch}}{\text{(amylodextrin)}}$$

The reader will note the contradictory statement concerning the color reaction o amylodextrin and the ambiguity of the references to starch glycerite and soluble starch. Until we understand the above re actions and can compare the spectral pro files of the reaction products, the term *modi fied starch glycerite* will be used arbitraril in reference to the soluble starch-glyceri indicator described herein.

The indicator is prepared as follows:

1. Add 3 g of powdered soluble starc to 100 ml of glycerin and heat t 190°C.
2. Remove from heat and cool to roo temperature. Developing turbidit may be ignored as it does not inte fere with the efficacy of the indicato

If the solution should gel with age reheat to 190°C and dilute with small amount of glycerin. Use 1 to 2 drops per 100 ml sample.

This indicator has been in use at this and other laboratories for approximately eight months. The solutions have been exposed to conditions favorable to deterioration such as exposure to light, air, etc. To date, there has been no indication of any deterioration. The color developed with a drop of the indicator is an intense blue with a sharp end point.

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The Yellow Perch of Lake Erie

#81

By HARRY D. VAN METER*

IN SOME lakes yellow perch become so abundant that neither they nor other fish can thrive; these waters are said to be "perch-bound". The population generally becomes so stunted that corrective measures, such as the total destruction of the fish population followed by restocking with more suitable species, must be taken if fishing is to improve. This is not to suggest that Lake Erie is in such a predicament or likely to approach it. It is readily acknowledged, however, that the lake now contains a vast and widespread perch population probably larger than at any previous time. With the possible exception of smelt, the numbers of perch are unsurpassed by any other game or commercial fish in the lake.

The yellow perch long has been a significant element in the fish population of Lake Erie. In fact, the prolific perch are known to have contributed rather consistently to commercial landings from the very start of the fishery. Statistical accounts that date back to the 1860s record many a generous yield. Even so, it has been only during the last two years that the production of perch has really come into its own.

A quick look into the U. S. commercial catch records for yellow perch over the past 30 years shows a range from 1,250,000 to 14,000,000 pounds landed annually. With the exception of 1939 and 1945 the perch has ranked among the top five species in landings every year. In addition, yellow perch yielded the highest catch of any species in 1934 and 1941 and for every year since 1956. The Canadian catch records follow a similar pattern.

THE COMBINED U. S. and Canadian landing of yellow perch for 1959 (over 27 million pounds) although below the record output of cisco, compares favorably with the all-time high catches of blue pike and walleye. The year 1960 will undoubtedly show a decrease in the catch of perch—not because of any real scarcity but rather because they have not been landed at times when they were readily available. A low market price has so restricted the harvesting of this plentiful supply that fishing is marginal today. Of course, many other vital factors are involved in the distress of the industry—the decline of more preferred species and higher labor and equipment costs. However, the point is that a mere abundance of perch contributes little, if any, relief.

On the other hand, the sport fishery is making intensive and enthusiastic use of the great abundance of perch. They are being caught by anglers with relative ease practically the year round. No really accurate estimate of the total catch of perch by sport fishermen is possible at this time. Some authorities believe, however, the annual angler take might conceivably approach that of the commercial fishery. The Ohio Division of Wildlife conducted a sport-fishing survey in the western part of Lake Erie (1957 and 1958). Although the range of the survey was limited, it revealed that Ohio anglers were catching three times as many perch as all other species of fish combined. This ratio is probably much the same for all Lake Erie.

Old-timers, though in agreement that the yellow perch has reached a high level of availability, maintain that similar periods of abundance have taken place before, and further believe that the perch can quickly become scarce again. The prediction of future trends is hazardous, but there is little question that the yellow perch has for the moment more than filled the niche vacated by other and more favored species. What happens over the next several years will be followed closely and with great interest by everyone concerned.

Knowledge of the biology of the yellow perch is extensive but by no sense complete. Various phases of its life history have been investigated by a number of individuals. One of the more extensive Lake Erie studies concerns its age and growth in relation to production through 1948*.

ADDITIONAL DATA collected in subsequent years are being compiled to detect any changes that may have since occurred. Thus far, more than 6,900 scale samples collected in 1949-1959 have been examined for the determination of age and year-class contributions.

Although the analyses of the material have been only preliminary, several significant facts have been brought out. A few yellow perch begin entering the commercial fishery toward the end of the second summer of life (age one). Most perch, however, enter as two-year-olds and some continue available to the fishery as long as another three years. The percentage of older fish is drastically reduced beyond age-group four; no perch older than age six were taken in the Lake Erie sampling. The vast majority of perch landed each year are ages two and three; the former normally dominate the catches. Length-frequency data for the different age groups reveal that most age two perch fall into the eight to 9½-inch group, age three fish within the nine to 10½-inch grouping, and those of age four in the 10 to 11-inch size range. The largest specimen collected during the past 10 years was an age six fish 13.3 inches long, and weighing 31 ounces. Larger ones are known, however, to have been taken by fishermen.

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* *"Age, Growth, and Production of Yellow Perch in Lake Erie," by Frank W. Jobes, Fish. Bull. U. S. Fish and Wildlife Serv., Vol. 52 (Bull. 70), pp. 205-206, 1952.*

Yellow perch of Lake Erie mature at a relatively small size and early age. A high percentage of the yearling males (averaging less than five inches long) examined last spring were capable of spawning. Few females, on the other hand, mature before they are seven inches or longer. Both sexes are predominantly mature under the eight and one-half inch minimum size limit imposed on the commercial fishery. It is apparent that size limit is not required for the protection of spawners; it does, however, have a certain value to the economics of the fishery.

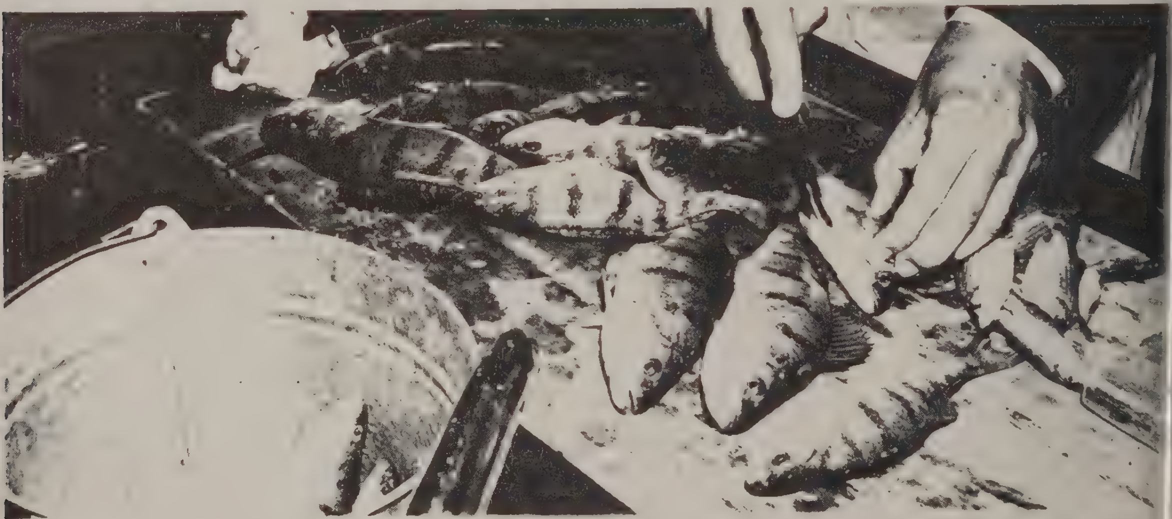
The shallow depth and fertile water of Lake Erie appear to provide an environment eminently suitable for yellow perch. Evidence for this belief comes from the considerable abundance of perch in all parts of the lake. Distribution of perch is nevertheless not uniform and segregation occurs within the population. In general, perch are more plentiful in the western than in the eastern end of the lake. Within the perch population small fish live in shallower water than do large ones and the larger perch segregate strongly according to sex.

THE VERSATILE food habits of the yellow perch contribute strongly to its success in competition with most other fishes. Foods taken include zooplankton (microscopic animals), insect adults and larvae, snails, clams, crayfish, and small fish. Zooplankton and midgefly larvae usually make up a substantial part of the diet especially among smaller perch. Food taken seems to be a matter of availability and size rather than any particular preference for one type over another. The size is of considerable importance in the diet of the larger perch. Perch usually stay at or near the bottom and feeding takes place ordinarily during the daylight hours.

Spawning of the yellow perch usually occurs during the early part of May as the water temperature reaches 45° to 50° F. A single female, depending on size, may deposit from 10,000 to 40,000 eggs which are easily recognized by being contained in long, flat, ribbon-like masses. Incubation normally requires about two weeks. The resulting fry grow very rapidly and young-of-the-year attain an average length of about four inches by late fall.

Trawling conducted by biologists of federal and state agencies over the past four years have disclosed a good hatch and survival of yellow perch each year. Frequently several thousand small fish (mostly young-of-the-year and yearlings) are caught in a single 10-minute tow. Extensive sampling records show that young-of-the-year were more plentiful in 1958 than in 1957 and that 1959 reproduction was even greater—indeed truly outstanding. Although the 1960 findings are incomplete, the early catches point to another good year.

IT APPEARS that Lake Erie will be teeming with yellow perch for some time to come—possibly at the expense of other desirable species. It is to be hoped that this soaring population can maintain its present fast growth rate so that the abundance of good-sized perch will continue to be available to commercial and sports fishermen. Fishermen should not be surprised, however, if abundance declines at some later time, and should not be too quick to ascribe the change to overfishing, pollution, or some other man-made cause.



INFORMATION on the sex ratio and food contents of yellow perch and other species is taken periodically. Photograp
by Don Miller, Elyria Chronicle-Telegram.

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ABUNDANCE OF ST. JOHNS RIVER SHAD[1]

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Scientific management of our fishery resources to obtain optimum sustained yields has been the object of much fishery research in recent years. Management of fisheries to increase long-term yield is possible, at least for some species, as evidenced from West Coast research on the Pacific halibut *(Hippoglossus stenolepis)* and the sockeye salmon *(Oncorhynchus nerka),* and from East Coast research on the shad populations of the Hudson and Connecticut Rivers. The success of these studies was dependent on knowledge of population size determined over a period of years. With these data, it was possible to conduct studies which were successful in determining causes for fluctuations in population abundance. The control of factors limiting population size, within desired levels, has led the way to successful fisheries management.

An investigation to determine the feasibility of managing the shad population of the St. Johns River, Florida, was begun in 1953. This program is part of a coastwise study of the American shad *(Alosa sapidissima)* begun by the U. S. Fish and Wildlife Service in 1950 and sponsored by the Atlantic States Marine Fisheries Commission.

LIFE HISTORY

The American shad is an anadromous fish which spends most of its life in the sea, but spawns in the fresh waters of our coastal rivers. The range of this species on the Atlantic Coast is from the St. Lawrence River in Canada to the St. Johns River in Florida. The spawning migration begins as early as November in Florida and as late as June in Canada. Females deposit their eggs loosely in the water where they are fertilized by the males. The number of eggs produced per female has been found to range from 116,000 to 660,000, depending on length, weight, and age of the fish. After absorbing water, the eggs sink to the river bottom where they are carried by the current. Hatching occurs in 6 to 8 days, depending on water temperature.

According to Talbot and Sykes (1958), shad native to streams north of Cape Hatteras, N. C., which survive spawning migrate to the sea and in successive years return to spawn again, provided they survive natural and fishing mortalities. Those fish native to streams south of Cape Hatteras die after spawning.

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[1] This report embodies some of the results of a paper submitted for publication as a Fishery Bulletin, U. S. Fish and Wildlife Service, and includes additional data for 1959.

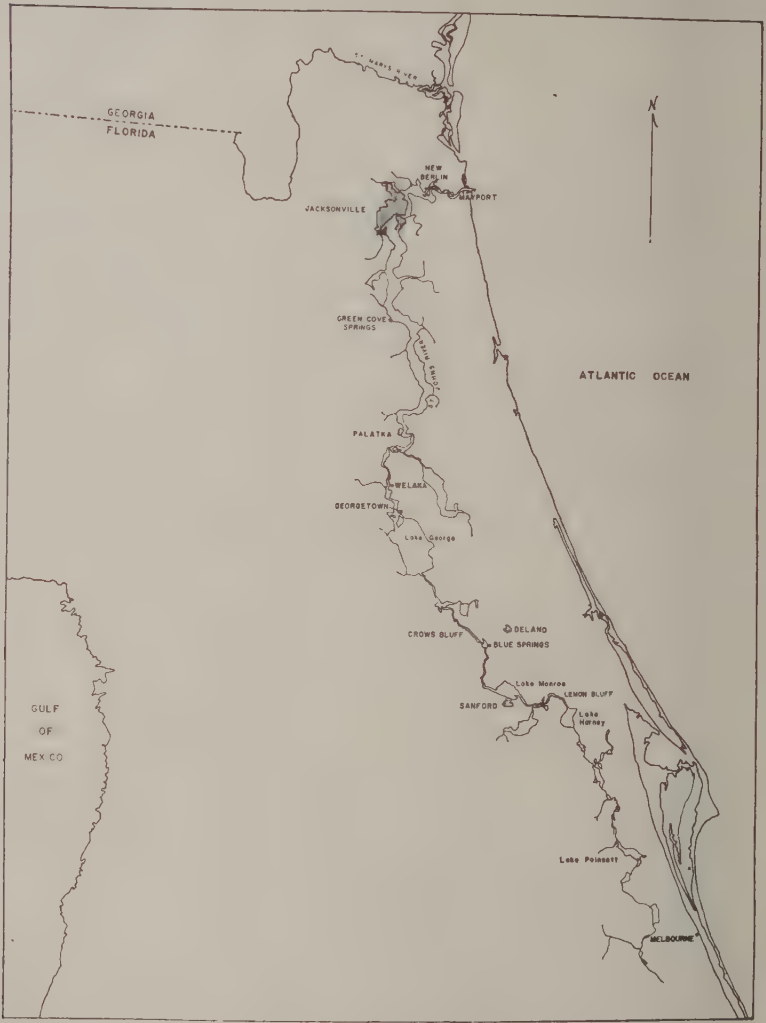
ST. MARYS RIVER
GEORGIA
FLORIDA
N
NEW BERLIN
MAYPORT
JACKSONVILLE
GREEN COVE SPRINGS
ST. JOHNS RIVER
ATLANTIC OCEAN
PALATKA
WELAKA
GEORGETOWN
Lake George
DELAND
CROWS BLUFF
BLUE SPRINGS
Lake Monroe
LEMON BLUFF
SANFORD
Lake Harney
GULF OF MEX CO
Lake Poinsett
MELBOURNE

Figure 1. St. Johns River, Florida.

The young remain in the rivers until fall, at which time they are 3 to 6 inches in length, and then enter the ocean. The summer and fall months are spent in the Gulf of Maine and the winters in deep water off the Middle and South Atlantic Coast. After attaining sexual maturity, in 3 to 5 years, most shad return to the stream of their birth to complete the cycle. The age of shad and number of times they spawn can be determined from their scales (Cating 1953).

DESCRIPTION OF RIVER AND FISHERY

The St. Johns River originates about 50 miles north of Lake Okeechobee and 15 miles southwest of Melbourne, Florida. It flows north through a number of shallow lakes to Jacksonville and then east to the ocean for a total length of about 285 miles. In this river, shad fishing is limited to several well-defined areas. Anchor-gill nets are fished in the ocean in close proximity to the river mouth. Drift-gill nets are fished in the vicinity of both Jacksonville and Palatka. Haul seines (locally termed ''shad nets'') are fished between Palatka and Welaka. In addition to the commercial fishery, there is an extensive sport fishery for shad located between Lakes Monroe and Harney (Fig. 1).

Commercial fishing for this species did not begin on the St. Johns until 1858 when a fisherman from Connecticut began fishing near Mayport at the mouth of the river. In 1880, the first year in which total catch records are available, 252,000 pounds were reportedly caught (Table 1). Since that time the catch increased to a peak of

TABLE 1. COMMERCIAL CATCH OF SHAD IN THOUSANDS OF POUNDS, ST. JOHNS RIVER, FLORIDA[1]

Year	Catch	Year	Catch
1880	252	1939	254
1888	1,448	1940	344
1889	2,051	1941	256[3]
1890	2,654	1942	323[3]
1896	1,375[2]	1943	666[3]
1897	1,011	1944	811[3]
1902	1,819	1945	842
1908	2,833	1946	837[3]
1918	964	1947	625[3]
1923	503	1948	515[3]
1927	348	1949	284[3]
1928	691	1950	298
1929	701	1951	336
1930	880	1952	203
1931	621	1953	280
1932	546	1954	343
1934	782	1955	434
1936	282	1956	293
1937	288	1957	261
1938	299	1958	552
		1959	604

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[1] Statistics 1880-1952 from Power (1958), except as noted. Statistics 1953-1959 this study.
[2] Catch in fish 1896 (Stevenson, 1899) converted to pounds by factor of 3.0.
[3] Catch data obtained by Florida State Board of Conservation.

2,833,000 pounds in 1908 and then decreased with minor fluctuations to a low of 203,000 pounds in 1952. Except for the period, 1953-1959, no data are available concerning the amount of fishing gear employed in making these catches, and therefore it is impossible to say whether fluctuations in catch were caused by changes in shad abundance, changes in fishing effort, or a combination of these factors.

POPULATION STUDIES

Since 1953 the U. S. Bureau of Commercial Fisheries has been studying the shad population of the St. Johns River. Each year catch and effort data have been obtained from both the commercial and sport fisheries. The commercial catch data are obtained from fish buyers who keep a daily record of all fish purchased. Data on the sport catch are obtained from several camp operators who keep a record of the number of their boats rented and the number of shad landed.

During the 1958 shad run an intensive tagging and recovery program was conducted in the upriver-haul-seine-fishing area to determine fishing rate and size of run available to this fishery. Normally a tagging study to estimate population size would be conducted near the river mouth. In this river, however, live fish suitable for tagging could not be obtained from the lower-river-gill-net-fishery, and therefore the study was conducted from haul seines. Throughout the fishing season, 950 shad were tagged with Petersen disk tags inserted directly below the origin of the dorsal fin. Care was taken that only vigorous fish were tagged, and therefore tagging mortality was considered negligible. Fishermen were contacted frequently during the fishing season in an effort to recover all recaptured tags. A 50-cent reward was paid for the return of each tag.

Ninety-seven of the fish tagged were recovered downstream by the gill-net fishery. The majority of these were taken in the Palatka area. Since the purpose of the tagging program was to determine the number of tagged shad available to the haul-seine fishery, these 97 tags were subtracted from the total tagged, leaving 853 available to the fishing gear. No tags were recaptured outside the river; therefore it was assumed that most, if not all, tagged fish that moved downstream immediately after tagging, eventually resumed their upstream journey to the spawning grounds. During the fishing season, 108 tagged fish were included in the 344,000 pounds of shad which were taken by the haul seines. The estimated fishing rate of these nets was 108/853, or 12.7 percent. Because of the small mesh size of the haul seines, all shad encircled by this gear were considered captured regardless of whether they were tagged or untagged, and therefore tag selectivity was nil.

An estimate of the number of shad available to the haul seine fishery was obtained by dividing the catch (344,000 pounds) by the calculated fishing rate (12.7 percent). The value obtained was 2,709,000 pounds. Ninety-five percent confidence limits on this estimate were calculated to be 2,223,000 and 3,260,000 pounds (Chapman, 1948).

The information obtained from the 1958 studies can be used to obtain estimates of the size of run available to the haul seine fishery for each year in which catch and effort data have been obtained, provided several assumptions pointed out by Ricker (1940) are satisfied. Analysis of data obtained from this investigation indicates that this was done. Using a method given by Talbot (1954), the fishing rate and number of shad available to the haul seines were determined for each year since 1953. Total effort, fishing rate, catch, and estimated size of run available to the haul-seine fishery are given in Table 2. Also shown in the table is the estimated size of the St. Johns River shad population for the years 1953-1959. This was determined by adding the number of fish caught by the gill-net fishery to the number available to the haul seines. From inspection of Table 2, it is evident that since 1953 both catch and population size have generally increased while fishing effort has generally decreased.

TABLE 2. CALCULATED NUMBER OF SHAD AVAILABLE TO THE HAUL-SEINE FISHERY AND ESTIMATED POPULATION SIZE, ST. JOHNS RIVER, FLORIDA

	Haul seine				Gill net	Population
Year	Effort (net-days)	Fishing rate (per cent)	Catch (thousands of pounds)	Size of run (thousands of pounds)	Catch (thousands of pounds)	size (thousands of pounds)
1953	785	22.1	201	910	79	989
1954	616	18.0	261	1,450	82	1,532
1955	492	14.5	381	2,628	53	2,681
1956	303	9.2	174	1,891	119	2,010
1957	224	6.9	182	2,638	79	2,717
1958	426	12.7	344	2,709	208	2,917
1959	481	14.3	392	2,741	212	2,953

Fish escaping the commercial fishery are still liable to capture by the upstream sport fishery. Sport fishing for shad on the St. Johns began in 1942. Since that time it has grown and at present is the largest sport fishery for this species on the Atlantic Coast. Shad are taken by hook and line from December through April; however, the best catches are made from mid-January to mid-March. A creel census conducted on this fishery in 1958 indicated that the catch was 65,000, or about 175,000 pounds of fish. This information, together with partial census data collected since 1953, was used to obtain estimates of the sport catch each year 1953 to 1959. The annual catch of shad in the St. Johns River was obtained by adding the commercial and sport catch for the same year. The number of shad not caught each year, termed the spawning escapement, was estimated by subtracting total catch from population size. Annual fishing mortality rate was obtained by dividing total catch by size of run. From Table 3 it can be seen that the sport catch has increased from 82,000 pounds in 1953 to 181,000 pounds in 1959. Total catch has generally increased from 362,000 pounds in 1953 to 785,000 pounds in 1959. During this same period, spawning escapement generally increased from 627,000 to 2,169,000 pounds. The annual fishing mortality rate decreased from 37 percent in 1953 to 15 percent in 1957, with an increase to 26 percent in 1959.

TABLE 3. POPULATION STATISTICS OF SHAD RUNS, ST. JOHNS RIVER, FLORIDA

Year	Sport catch (1,000 pounds)	Total commercial and sport catch (1,000 pounds)	Population size (1,000 pounds)	Spawning escapement (1,000 pounds)	Fishing mortality rate (per cent)
1953	82	362	989	627	37
1954	74	417	1,532	1,115	27
1955	90	524	2,681	2,157	20
1956	64	357	2,010	1,653	18
1957	140	401	2,717	2,316	15
1958	175	727	2,917	2,190	25
1959	181	785	2,953	2,169	26

DISCUSSION

Scientific management of the St. Johns River shad population to obtain optimum yields is not now possible because factors affecting size of run are unknown. A number of elements could have an effect on the population by either increasing or decreasing its size. Some examples are fishing, pollution, water temperature, stream flow, predation, and competition. Since the magnitude of the population is known for only 7 years, no conclusions can be made as to causes for fluctuations in abundance. After population parameters have been determined for an additional number of years, hypotheses may be formulated to account for changes in abundance. If factors affecting these changes can be determined and controlled, the St. Johns River shad population can then be managed on an optimum sustained yield basis. However, if they cannot be controlled, their effect could probably be predicted and the fishery managed accordingly.

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DISCUSSION

MR. FRANK [Connecticut]: I would like to know how long of an open season you allow for sports fishing of shad and how long you allow for nets.

MR. WALBURG: Well, I am not a resident of Florida. However, they have no closed season on the taking of shad by sport tackle. That was instigated three years ago. The commercial fishing season runs from November 15 until March 1, but may be extended for one to two weeks, at the discretion of the commissioners.

The shad spawn in the St. John's River. The spawning run begins as early as November, but spawning actually doesn't begin until February and continues into April.

MR. FRANK: Is that fish basically the same in size and firmness of the flesh as it is up North?

MR. WALBURG: I would say so, until the water temperature gets rather warm and then, of course, it becomes soft. In February and March, when water temperatures are relatively cool, it is still the same caliber of fish that we catch up North.

MR. HANSEN [Oregon]: I would like to know if you have had any trouble in any of the commercial fisheries there with incidental catches. Out in the Goose Bay area of Oregon, we have the striped bass that intermingles with the shad at spawning time. As a result, there is a considerable catch of striped bass in connection with shad fishing there. Have you had this trouble?

MR. WALBURG: No. The only trouble we have had is with taking other game fish, such as the bream, which are supposed to be released when they are caught. However, some of these other fish which are of no value are merely thrown up on the bank. We have had no problem with the striped bass.

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ROLAND L. WIGLEY

U. S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries, Biological Laboratory, Woods Hole, Massachusetts

The genus *Chiridotea* is unique to the eastern coastal region of the United States and southeastern Canada. Members of this genus are small (usually < 1 cm.), broad, depressed valviferous forms that inhabit sandy areas and characteristically burrow just beneath the sediment surface. The species described herein constitutes the fourth known species of this genus. Those previously described are: *C. coeca* (Say, 1818); *C. tuftsi* (Stimpson, 1853); and *C. almyra* Bowman, 1955. Included in Bowman's paper is a revision of the generic characteristics of this group. The description of this new form is based on specimens collected on Georges Bank, a relatively shallow portion of the continental shelf east of Massachusetts, U. S. A. These specimens were encountered while processing collections of benthic invertebrates taken by the R/V *Albatross III* and the R/V *Delaware* for the Woods Hole Laboratory, Bureau of Commercial Fisheries, U. S. Fish and Wildlife Service.

Material Examined.—Holotype, adult female with oostegites developed, 7.5 mm. in length, deposited in the U. S. National Museum (Catalogue No. 104282); allotype, adult male 6.0 mm. in length (U.S.N.M. Catalogue No. 104280); paratypes, 1 male 5.0 mm. in length and 1 ovigerous female 6.5 mm. in length (U.S.N.M. Catalogue No. 104281); all type specimens were collected August 6, 1959, by means of a grab-type bottom sampler on Georges Bank at lat. 41° 48′ N., long. 67° 53′ W.; water depth 15 fathoms, sand substrate, bottom water temperature 57.0° F. (R/V *Delaware,* cruise number 59-9, station 21).

One female, 7.5 mm. in length, collected December 7, 1955, at lat. 40° 51′ N., long. 68° 55′ W.; substrate coarse sand, water depth 36 fathoms, bottom water temperature 47.2° F. (R/V *Albatross III,* cruise number 70, collection 3).

One male, 6.5 mm. in length, collected December 14, 1955, at lat. 41° 40′ N., long. 67° 36′ W.; substrate gravelly sand, water depth 28 fathoms, bottom water temperature 45.7° F. (R/V *Albatross III,* cruise number 70, collection 38).

Five females, body lengths 4.0, 5.0, 6.5, 7.5, 7.5 mm., and two males, body lengths 7.0 and 7.0, collected August 24, 1957, at lat. 41° 22′ N., long. 68° 20′ W.; substrate coarse sand, water depth 24 fathoms (R/V *Albatross III,* cruise number 101, station 64).

Three specimens, 4.0, 4.5, 4.5 mm. in length, collected August 24, 1957, at lat. 41° 34′ N., long., 67° 28′ W.; substrate coarse sand, water depth 23 fathoms (R/V *Albatross III,* cruise number 101, station 90).

Diagnosis.—Medium-sized *Chiridotea* with short antennae; flagellum of antenna 2 is much shorter than the peduncle; antenna 1 usually not reaching beyond the peduncle of antenna 2; outer margin of pereion epimeral plates 5–7

Figures 1–9. *Chiridotea arenicola* n. sp.

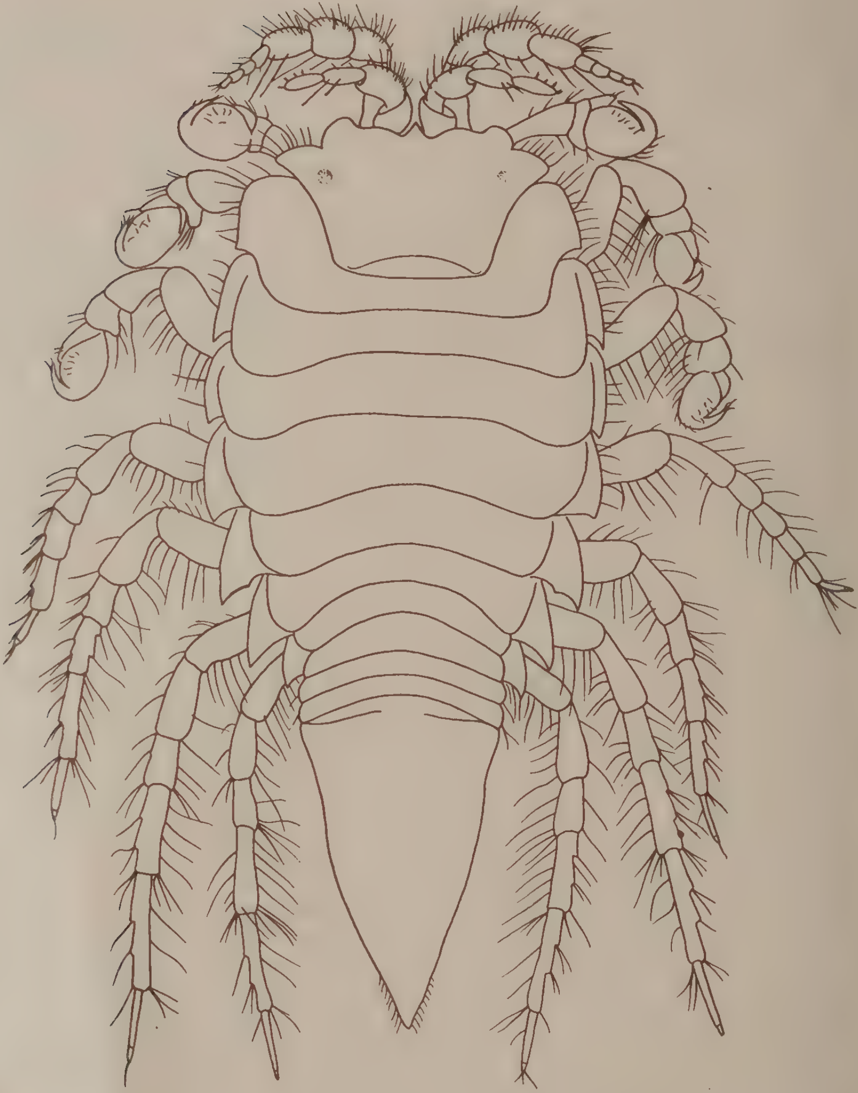

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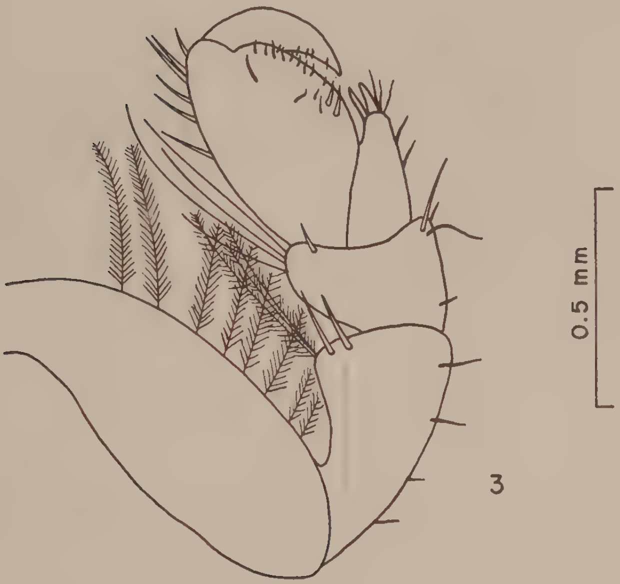
Figure 1. Dorsal view of female holotype.



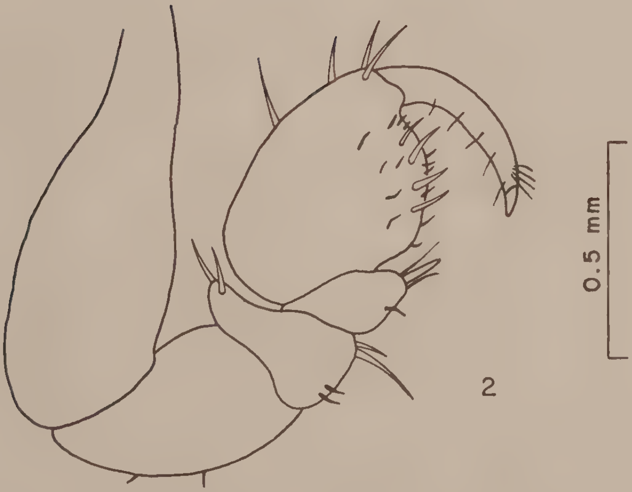


Figure 2. Pereiopod 1, ♂.
Figure 3. Pereiopod 2, ♂.

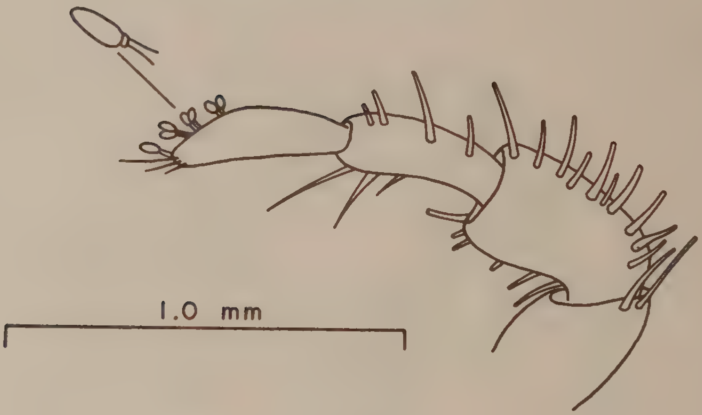


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Figure 4. Antenna 1, ♂.

with relatively few or no setae. This species most closely resembles *C. coeca* (Say) but differs in that it is smaller, the pereiopods are more slender, the body is thinner and less convex dorso-ventrally, the pleotelson is narrower and more evenly tapered, and the anterior lobes of the antero-lateral sections of the head are shorter and have margins devoid of setae. Other differences are mentioned later in this paper under the heading *Discussion.*

Description.—Anterior margin of head broadly and shallowly excavated each side of the rostrum. Lateral anterior projections on the head are rounded or obtusely pointed. Pronounced, but comparatively shallow, V-shaped notch in each antero-lateral margin of the head; margin anterior to the notch is without

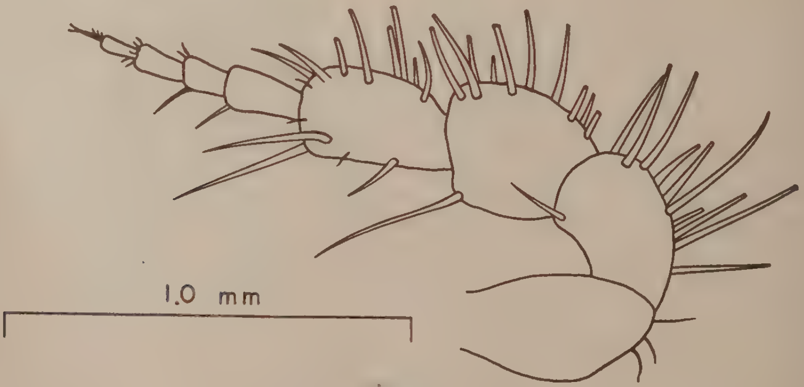

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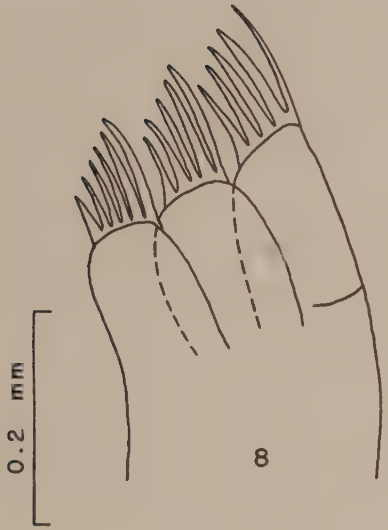
Figure 5. Antenna 2, ♂.



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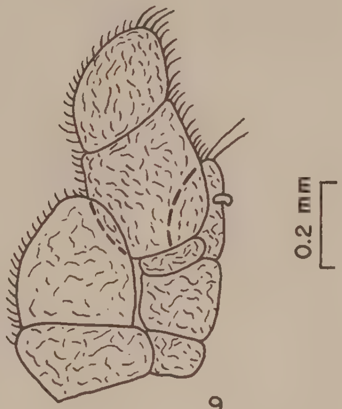

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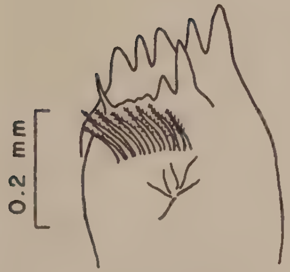

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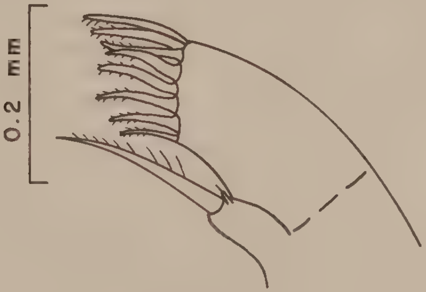

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Figure 6. Left mandible, ♂.
Figure 7. Maxilla 1, ♂.
Figure 8. Maxilla 2, ♂.
Figure 9. Maxilliped, ♂.

setae, the margin posterior to the notch has approximately 6 setae. The anterior lobe does not extend outwardly as far as the posterior lobe. Rather small, irregularly rounded compound eyes are located dorsally on the head near the base of the postero-lateral lobe; they are only faintly visible in many of the specimens examined. Epimeral plates distinct on pereion somites 2–7, their postero-lateral margins acutely produced posteriorly; this projection is more pronounced on plates 5–7 than on plates 2–4. Stout setae fringe the lateral margins of pereion somite 1 and epimeral plates 2–4, and are sparse or absent on plates 5–7. Pleotelson elongate, its length is about 1.6 times its width at the base; sides of the pleotelson taper somewhat irregularly from the base to the apex; lateral margins near the apex are very finely denticulate and beset with setae. General body proportions are: body width 0.43 times body length; abdomen length 0.45 times body length; head length about 0.17 times body length.

Antenna 1 is short, extending only to about the end of the peduncle of antenna 2; the flagellum consists of 1 segment and it usually bears 4 pairs of inflated setae on the anterior margin. Antenna 2 is only slightly longer than antenna 1, its flagellum is made up of 3–5 segments. First segment of the peduncle is expanded; second segment with the distal two-thirds expanded; third segment elongate and slender, approximately equal in length to the flagellum. Maxilliped palp is composed of 3 segments. Maxilla 1 with the inner branch possessing a large, plumose seta and a minute seta. Mandible is without a molar process. Propodus of pereiopod 1 is 1.2 times as long as broad; posterior margin of dactyl 1 bears 4–6 fine setae; a few small setae are present on the external lateral surface of the propodus, near the posterior margin. The posterior (ventral) margin of the carpus of pereiopod 1 is armed with only one stout spine. Pereiopods 1, 2, and 3 are generally similar in conformation and embellishment; likewise, pereiopods 4, 5, 6, and 7 resemble one another.

Color.—Basic color of the body and appendages ranges from light tan or a pinkish hue to nearly white with the integument partially covered with dark chromatophores. The chromatophores are black or deep violet and are distributed somewhat unevenly over the body and the larger exposed appendages. Chromatophores are not evident on the pleopods or the inner mouth parts. In the material studied, much variation was observed in the pigmentation pattern from one specimen to another; however, in all specimens examined the chromatophores are consistently more densely concentrated on the uropods and pleotelson than on other parts of the body. Differences in pigmentation appear to be unrelated to size, sex, or season of capture.

Range.—Georges Bank (east of Massachusetts, U. S. A.) in water depths 15 to 36 fathoms and water temperature 45.7° to 57.0° F.

Discussion.—Shape of the head in *C. arenicola* is quite like that found in *C. almyra*. The posterior portion is comparatively long and somewhat narrowed, and the antero-lateral lobes are rather short. The notch separating the antero-lateral margin into two lobes is shallow, as compared to related species. *C. arenicola* is distinguished from all other species in this genus by the absence of setae on the anterior lobe of the antero-lateral margin of the head.

The propodus of pereiopod 1 in *C. arenicola* is relatively short and wide, similar to that of *C. coeca,* but it lacks the setation on the outer central, lateral surface found in that species. The dactyl of pereiopod 1 has only a few thin setae on the occluded margin; in this feature it resembles *C. almyra* and *C. coeca*.

In *C. arenicola* the size and number of setae on the outer margin of epimeral plates 5–7 varies considerably from one specimen to another; however, these setae are generally shorter and much less numerous in this species than in other members of the genus. A slight sexual dimorphism in this feature is apparent in the few specimens available for study. The setae appear to be longer and more numerous in large males than in adult females and small males.

The shape of the pleotelson of *C. arenicola* is intermediate between that of *C. coeca,* which is broad and tapers irregularly, and that of *C. tuftsi,* which is rather narrow and evenly tapered.

The eye is dark and distinct in some specimens and faint in others. Variation in this characteristic occurs at random among the sexes, specimens of various sizes, and in different collections (some of which have been in preservative for two months and others nearly two years). In the specimens at hand, the eye appears to be proportionately much smaller in *C. arenicola* than that depicted for *C. coeca* by Bousfield (1956).

To my knowledge neither *C. almyra* nor *C. coeca* have been reported from offshore waters, and they have not been observed in our collections of benthic invertebrates from the Georges Bank area. *C. arenicola* and *C. tuftsi* are the only representatives of this genus found in our samples taken during the past few years. Of these two species the latter is far more numerous than *arenicola;* a ratio of approximately 20:1, based on the total number captured. Our records indicate that *C. tuftsi* is rather widely distributed over Georges Bank and nearly always within the 50-fathom isobath. *C. arenicola* seems to be more restricted, having been taken only near the shoals on the north-central part of Georges Bank and on the western end near Great South Channel.

A factor which appears to be important in affecting the distribution of these two species is the particle size composition of the substrate. *C. arenicola* has been taken most frequently from areas where the predominant sediment fraction is a coarse sand (0.5–1.0 mm.). Conversely, *C. tuftsi* is most commonly found where the predominant sediment fraction is a medium sand (0.25–0.5 mm.). Also, there is some evidence that *C. arenicola* either burrows more deeply into the sand or for some other reason is more difficult to evict from the substrate than *C. tuftsi*. This inference is based on two factors: (1) in dredges that normally scrape only the surface of the sea bed, hundreds of *tuftsi* have been caught, compared to only two specimens of *arenicola;* (2) in grab-samplers that usually dig 3 to 6 inches into the sea floor, 10 specimens of *arenicola* have been taken, versus 7 specimens of *tuftsi.*

Some of the more common Crustacea with which *C. arenicola* has been found associated are the amphipods: *Aeginina longicornis* (Kröyer), *Ampelisca spinipes* Boeck, *Amphiporeia virginiana* Shoemaker, *Ericthonius rubricornis* Stimpson, *Haustorius arenarius* (Slabber), *Leptocheirus pinguis* (Stimpson), *Photis dentata* Shoemaker, *Pontogeneia inermis* (Kröyer), *Podoceropsis nitida* (Stimpson), *Sympleustes glaber* (Boeck), and *Tmetonyx nobilis* (Stimpson); the mysid: *Neomysis americana* (Smith); and the decapods: *Cancer borealis,* Stimpson, *Cancer irroratus* Say, *Crangon septemspinosa* Say, *Dichelopandalus leptocerus* (Smith), and *Pagurus acadianus* Benedict. These species are the most abundant crustaceans that were taken in the same bottom-grab samples and dredge hauls with *C. arenicola.* It will be recognized that many of these associates are infauna forms; however, all of the larger species except one are epibenthic. Some species listed above are exceedingly tolerant and are adaptable to diverse environmental features, but others listed here are restricted to very specific types of habitats.

Judging from the information available at this time, it seems likely that *C. arenicola* will be found most closely associated with some of the burrowing amphipods listed above, such as *Amphiporeia, Haustorius,* and *Tmetonyx.*

KEY TO THE SPECIES OF CHIRIDOTEA[1]

1. Flagellum of antenna 2 much shorter than peduncle, segments 5 or less; antenna 1 nearly as long as antenna 2. 2

Flagellum of antenna 2 longer than peduncle, 8–12 segmented; antenna 1 much shorter than antenna 2. 3

2. Antenna 1 extends beyond peduncle of antenna 2; margin of anterior lobe of the antero-lateral margin of head is setose. .... *C. coeca*

Antenna 1 does not extend beyond peduncle of antenna 2; margin of anterior lobe of the antero-lateral margin of head is not setose. .... *C. arenicola,* n. sp.

3. Posterior margin of dactyl of pereiopod 1 armed with strong spines; pleotelson narrow, tapering evenly from base to apex. .... *C. tuftsi*

Posterior margin of dactyl of pereiopod 1 armed with a few fine setae; pleotelson broad, sides nearly parallel at the basal half. .... *C. almyra*

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[1] This key modified after that given by Bowman (1955).

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NOTE ON THE DISTRIBUTION OF PANDALIDAE (CRUSTACEA, DECAPODA) IN NEW ENGLAND WATERS

P 84

By

ROLAND L. WIGLEY

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INTRODUCTION

Four species of the family Pandalidae are common bottom-dwelling inhabitants of the offshore waters of New England; they are: *Dichelopandalus leptocerus* (Smith), *Pandalus borealis* Kröyer, *Pandalus montagui* Leach, and *Pandalus propinquus G. O. Sars.* Three additional species—*Plesionika tenuipes* (Smith), *Plesionika acanthonotus* (Smith), and *Heterocarpus carinatus* (Smith)—occur in New England waters, but because of their relative scarcity in the area sampled they will not be considered further in this report.

The 4 common species are rather large shrimps, the largest that occur in sublittoral waters of this region. Adults of all 4 species attain body lengths of 2 to 5 inches or more. The larger specimens are of a size presently acceptable for consumption in North America, although they are somewhat smaller than the Penaeidae—the shrimps commonly marketed in the United States and Canada. *Pandalus borealis,* the largest New England pandalid shrimp, supported a small commercial fishery in Maine and Massachusetts from 1933 to 1950 (Scattergood 1952). The fishing grounds for these stocks were limited to small coastal areas in the western Gulf of Maine, but as the abundance of shrimp diminished the fishery gradually terminated. However, assuming a continued market demand for shrimp, it may be anticipated that slightly smaller species may be sought in the future. Thus, there is a continued interest in the distribution and abundance of all New England pandalid shrimps.

A study of the more significant literature (Smith and Harger 1874; Smith 1879, 1881, 1882, 1884, 1887; R. Rathbun 1883; M. J. Rathbun 1905, 1929; Walford 1936;

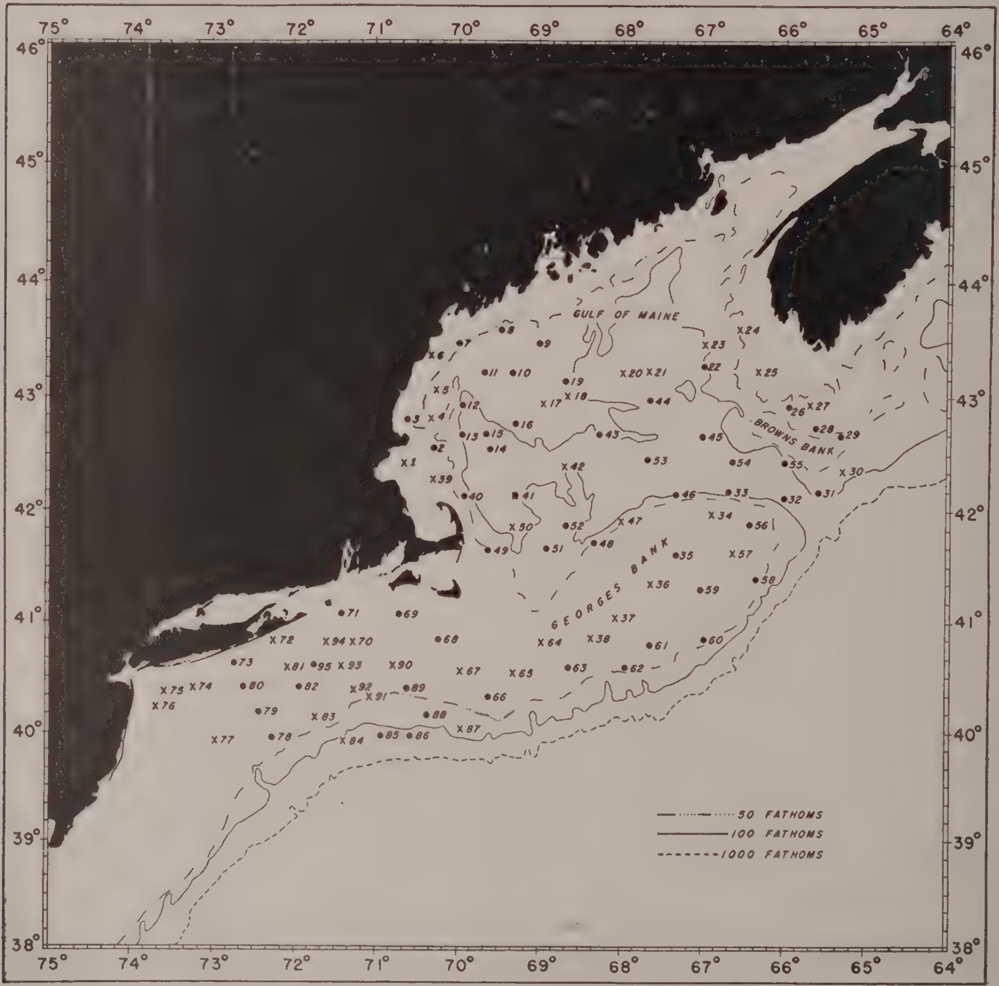
75° 74° 73° 72° 71° 70° 69° 68° 67° 66° 65° 64°
46° 45° 44° 43° 42° 41° 40° 39° 38°
GULF OF MAINE
BROWNS BANK
GEORGES BANK
x6 •7 •8 •9
•11 •10 •19 x20 x21 x23 x24 •22 x25
x5 x17 x18 •44 •26 x27
•3 x4 •12 •16 •13 •15 •43 •45 •28 •29
•2 •14 x1 x42 •53 •54 •55 x30
x39 •40 •41 •46 •33 •32 •31
x34 x50 •52 x47 •56
•49 •51 •48 •35 x57
x36 •59 •58
•71 •69 x37
x72 x94 x70 •68 x64 x38 •61 •60
•73 x81 •95 x93 x90 x67 x65 •63 •62
x75 x74 •80 •82 x92 x91 •89 •66
x76 •79 x83 •88
x77 •78 x84 •85 •86 x87
50 FATHOMS
100 FATHOMS
1000 FATHOMS

FIG. 1. Chart of New England region with trawling stations plotted. Stations where pandalid shrimp were caught are indicated by solid circles (●); stations where none were caught are indicated by crosses (x).

TABLE I. Station data and catch records of shrimp for *Albatross III* cruises 81 and 82, November 1956

Station	Date	Time (E. S. T.)	Latitude (north)	Longitude (west)	Water depth (fathoms)	Bottom water temperature (°F.)	NUMBER CAPTURED			
							Dichelopandalus leptocerus	Pandalus borealis	Pandalus montagui	Pandalus propinquus
1	2	1140	42°24′	70°40′	36	49.5	—	—	—	—
2	2	1525	42°33′	70°20′	62	46.0	4	1	—	—
3	2	1838	42°43′	70°36′	46	44.7	7	—	1	—
4	2	2145	42°49′	70°22′	75	42.6	—	—	—	—
5	3	0055	43°04′	70°18′	59	43.6	—	—	—	—
6	3	0350	43°20′	70°19′	24	49.0	—	—	—	—
7	3	0745	43°28′	69°58′	66	—	84	—	15	—
8	3	1110	43°38′	69°20′	70	—	1	—	—	—
9	3	1422	43°30′	68°59′	70	48.2	12	—	—	—
10	3	1713	43°14′	69°15′	90	42.8	—	1	—	12
11	3	2005	43°14′	69°36′	74	44.7	20	1	—	3
12	3	2220	42°58′	69°56′	106	—	—	2	—	—
13	4	0150	42°43′	69°56′	98	42.7	1	1	—	2
14	4	0500	42°33′	69°38′	143	44.9	2	—	—	3
15	4	0740	42°48′	69°39′	100	—	17	3	—	13
16	4	1024	42°50′	69°18′	42	43.2	45	—	—	—
17	4	1345	42°57′	68°58′	50	—	—	—	—	—
18	4	1715	42°58′	68°40′	102	45.0	—	—	—	—
19	4	1940	43°12′	68°38′	86	40.1	—	2	—	—
20	5	0010	43°13′	68°00′	124	—	—	—	—	—
21	5	0345	43°13′	67°39′	136	—	—	—	—	—
22	5	0820	43°14′	66°58′	102	—	—	—	1	58
23	5	1115	43°29′	66°58′	105	—	—	—	—	—
24	5	1423	43°36′	66°35′	56	54.0	—	—	—	—
25	5	1726	43°16′	66°19′	36	52.0	—	—	—	—
26	5	2125	42°58′	65°57′	70	47.1	—	—	4	—
27	6	0025	42°59′	65°40′	72	41.0	—	—	—	—
28	6	0250	42°42′	65°40′	50	49.5	1	—	64	—
29	6	0610	42°42′	65°18′	50	46.0	1	—	8	—
30	6	0822	42°24′	65°14′	62	40.0	—	—	—	—
31	6	1152	42°11′	65°35′	94	43.6	1	—	—	—
32	6	1430	42°10′	65°57′	124	—	19	—	3	3
33	6	1925	42°10′	66°35′	73	43.5	74	—	6	—
34	6	2215	41°54′	66°55′	33	52.7	—	—	—	—
35	7	0125	41°40′	67°16′	27	55.5	1	—	—	—
36	7	0545	41°22′	67°35′	19	55.2	—	—	—	—
37	7	0900	41°06′	67°56′	20	54.6	—	—	—	—
38	7	1100	40°50′	68°18′	20	55.6	—	—	—	—
39	8	1000	42°16′	70°18′	12	50.7	—	—	—	—
40	8	1215	42°10′	69°57′	78	42.0	11	2	—	—
41	8	1615	42°10′	69°22′	106	42.9	—	—	—	—
42	8	1915	42°25′	68°40′	108	43.0	—	—	—	—
43	8	2338	42°42′	68°19′	97	44.2	2	—	—	31
44	9	0400	42°54′	67°47′	97	43.8	5	—	—	34
45	9	0930	42°42′	66°58′	119	47.1	7	—	—	—
46	10	1315	42°09′	67°16′	79	44.0	28	—	—	—
47	10	1740	41°56′	67°55′	36	49.1	—	—	—	—
48	10	2045	41°44′	68°15′	30	—	90	—	—	1
49	13	2317	41°38′	69°38′	38	50.3	38	—	10	—
50	14	0220	41°54′	69°17′	107	42.2	—	—	—	—
51	14	0550	41°40′	68°58′	74	41.1	52	—	—	—
52	14	0830	41°53′	68°39′	93	41.6	7	—	—	—
53	14	1500	42°25′	67°38′	126	46.0	—	—	—	40
54	14	2030	42°28′	66°42′	180	46.0	30	—	—	56
55	15	0105	42°27′	66°00′	108	48.0	1	—	—	—
56	15	0600	41°54′	66°16′	47	52.3	1	—	—	—
57	15	0920	41°40′	66°36′	36	52.8	—	—	—	—
58	15	1230	41°28′	66°24′	51	52.3	1	—	—	—
59	15	1615	41°22′	66°57′	35	52.7	14	—	—	—
60	15	2028	40°52′	66°56′	50	60.7	24	—	—	—
61	16	0045	40°50′	67°36′	40	56.0	28	—	—	—
62	16	0405	40°36′	67°56′	48	63.0	61	—	—	—
63	16	0820	40°35′	68°36′	35	67.7	1	—	—	—
64	16	1125	40°50′	68°56′	37	61.8	—	—	—	—
65	16	1423	40°36′	69°16′	28	54.7	—	—	—	—
66	16	1840	40°20′	69°38′	38	63.5	14	—	—	—
67	16	2115	40°34′	69°58′	32	63.0	—	—	—	—
68	17	0030	40°50′	70°13′	20	53.0	17	—	—	—
69	17	0340	41°04′	70°45′	25	58.3	139	—	—	—
70	17	0727	40°51′	71°14′	32	—	—	—	—	—

TABLE I. (Continued)

Station	Date	Time (E. S. T.)	Latitude (north)	Longitude (west)	Water depth (fathoms)	Bottom water temperature (°F.)	NUMBER CAPTURED			
							Dichelopandalus leptocerus	Pandalus borealis	Pandalus montagui	Pandalus propinquus
71	17	1010	41°04′	71°24′	23	61.5	1	—	—	—
72	17	1445	40°52′	72°12′	16	59.0	—	—	—	—
73	17	1751	40°38′	72°44′	18	55.8	69	—	—	—
74	17	2117	40°23′	73°13′	18	56.6	—	—	—	—
75	17	2338	40°23′	73°34′	11	56.8	—	—	—	—
76	18	0200	40°14′	73°41′	18	—	—	—	—	—
77	18	1610	39°58′	72°58′	26	—	—	—	—	—
78	18	2040	39°56′	72°18′	38	58.0	5	—	—	—
79	18	2315	40°09′	72°25′	32	58.0	11	—	—	—
80	19	0138	40°22′	72°36′	26	56.0	29	—	—	—
81	19	0530	40°36′	72°06′	26	57.6	—	—	—	—
82	19	0720	40°26′	71°57′	36	61.0	1	—	—	—
83	19	1000	40°11′	71°46′	43	59.0	—	—	—	—
84	19	1235	39°58′	71°38′	59	56.8	—	—	—	—
85	19	1430	40°00′	70°54′	184	—	4	—	—	—
86	19	1850	39°58′	70°38′	186	—	7	—	—	—
87	19	2248	40°02′	70°00′	78	—	—	—	—	—
88	20	0210	40°06′	70°10′	64	57.6	2	—	—	—
89	20	0420	40°23′	70°34′	46	59.0	36	—	—	—
90	20	0655	40°38′	70°44′	34	61.0	—	—	—	—
91	20	1050	40°20′	71°04′	77	56.7	—	—	—	—
92	20	1315	40°22′	71°13′	43	62.0	—	—	—	—
93	20	1540	40°36′	71°23′	34	60.5	—	—	—	—
94	20	1610	40°50′	71°36′	32	62.0	—	—	—	—
95	20	2030	40°39′	71°44′	33	62.5	86	—	—	—
					Total number		1,112	13	112	256

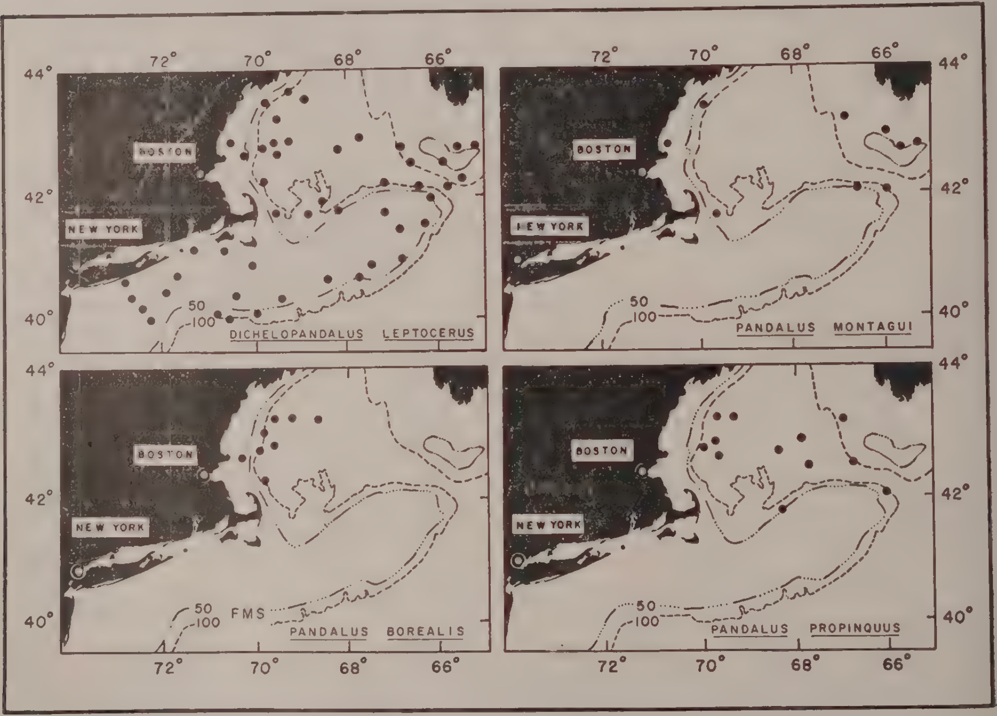
72°
70°
68°
66°
44°
42°
40°
BOSTON
NEW YORK
50
100
FMS
DICHELOPANDALUS LEPTOCERUS
PANDALUS MONTAGUI
PANDALUS BOREALIS
PANDALUS PROPINQUUS

FIG. 2. Geographic occurrence of the four most common species of New England pandalid shrimps, November 1956. Each dot represents a trawling station at which one or more specimens were caught.

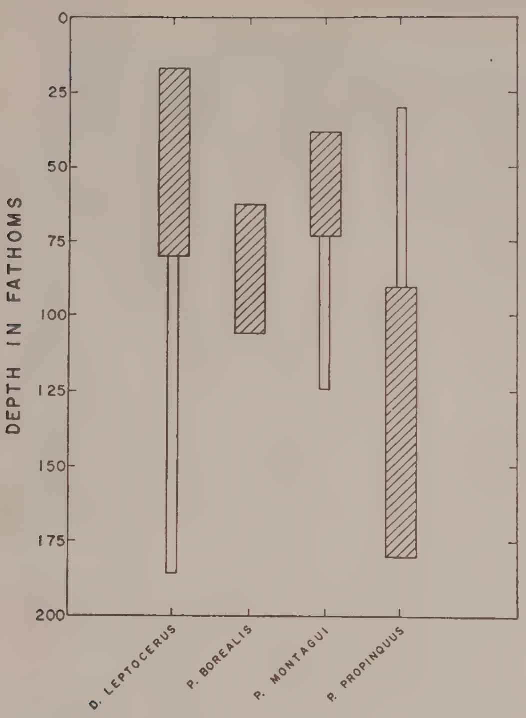

FIG. 3. Species occurrence in relation to water depth. Wide bar denotes 90 percent or more of the specimens; narrow bar denotes 10 percent or less.

Bigelow and Schroeder 1939; Whiteley 1948; Scattergood 1952) pertaining to the New England distribution of pandalid shrimps considered in this report has revealed rather few specific records of occurrence. The older publications usually cite few occurrence records and list them by species, whereas many of the more recent reports list more localities but group the species by genera or family. This literature is effectively summarized, in respect to geographic and bathymetric ranges, by M. J. Rathbun (1929) as follows:

Species	*Geographic range in western Atlantic Ocean*	*Bathymetric range (fathoms)*
Dichelopandalus leptocerus	Newfoundland banks to North Carolina	7-430
Pandalus borealis	Greenland to Cape Cod, Massachusetts	20-495
Pandalus montagui	Greenland to Rhode Island	3-430
Pandalus propinquus	Newfoundland banks to Delaware	34-1,089

MATERIALS AND METHODS

New occurrence records given in this report are based on collections taken November 2-20, 1956, during a groundfish survey conducted by the U. S. Fish and Wildlife Service, Woods Hole, Massachusetts. Collections of shrimp were made by personnel aboard the *Albatross III*, Cruises 81 and 82, at 54 of the 95 stations occupied in offshore waters on the continental shelf from Long Island northward to central Gulf of Maine and eastward to Cape Sable, Nova Scotia (Figure 1). Station data and collection records are listed in Table I.

A No. 36 otter trawl with an 80-foot groundrope and wooden rollers, plus the addition of a partial liner of ½-inch (extension measure) mesh, was employed in making all catches. Since this trawl is not designed for capturing shrimp, the numbers taken are probably minimal estimates of abundance. A standard tow of one-half hour duration was made at most stations. In the few cases where longer tows were made, catches were adjusted to the standard one-half hour period. The shrimp were preserved at sea and brought to the laboratory for identification.

Water depths were measured by means of a Bendix recording fathometer. The depths recorded in Table I are average values of the maximum and minimum soundings registered during each tow. A bathythermograph was used to determine bottom temperature. The temperature records, also included in Table I, are available for approximately 80% of the stations occupied.

I wish to thank Dr. John T. Conover, formerly with the U. S. Fish and Wildlife Service, and other staff members who collected the specimens and kindly placed them at my disposal.

RESULTS

Geographic Distribution

Catch records for the four species of pandalid shrimps are listed separately in Table I. The geographic occurrence of each species is illustrated in Figure 2. It is apparent from these charts that at this time of year each species has a characteristic geographic distribution. *D. leptocerus* is widely distributed over the entire area. This species is the only one common on Georges Bank and south of Cape Cod. *P. borealis* was taken only in a limited area in central and western Gulf of Maine. Of the 4 species, it has the most restricted geographic distribution within the study area. (Only 13 specimens of *P. borealis* were collected at 8 stations; therefore, the conclusions drawn for this species must be considered tentative.) *P. montagui* occurred around the perimeter of the Gulf of Maine with greatest numbers taken in the vicinity of Browns Bank. *P. propinquus* was found in the central Gulf of Maine and along the northern edge of Georges Bank. Since *D. leptocerus* inhabits the entire area sampled, it thus occurs at the same localities with the other 3 species. The distributions of the 3 species of *Pandalus* overlap one another along the fringes of their centers of abundance.

Bathymetric Distribution

The species distribution charts (Fig. 2), in which the 50-and 100-fathom isobaths are drawn, suggest that the geographic distribution of each species is related to water depth. This relationship is illustrated more clearly in Figure 3, a bar graph depicting species occurrence in relation to water depth. This illustration reveals that *D. leptocerus* inhabits a comparatively wide range in depth, from 18 to 186 fathoms. However, this species was most common in shallow and moderately shallow waters, between 18 and 80 fathoms, and was the only pandalid taken in water depths less than 30 fathoms. *P. borealis* occupied a relatively narrow stratum in moderately deep water. It was found only in depths between 62 and 106 fathoms. *P. montagui* was most common in depths between 38 and 73 fathoms, with 3 speci-

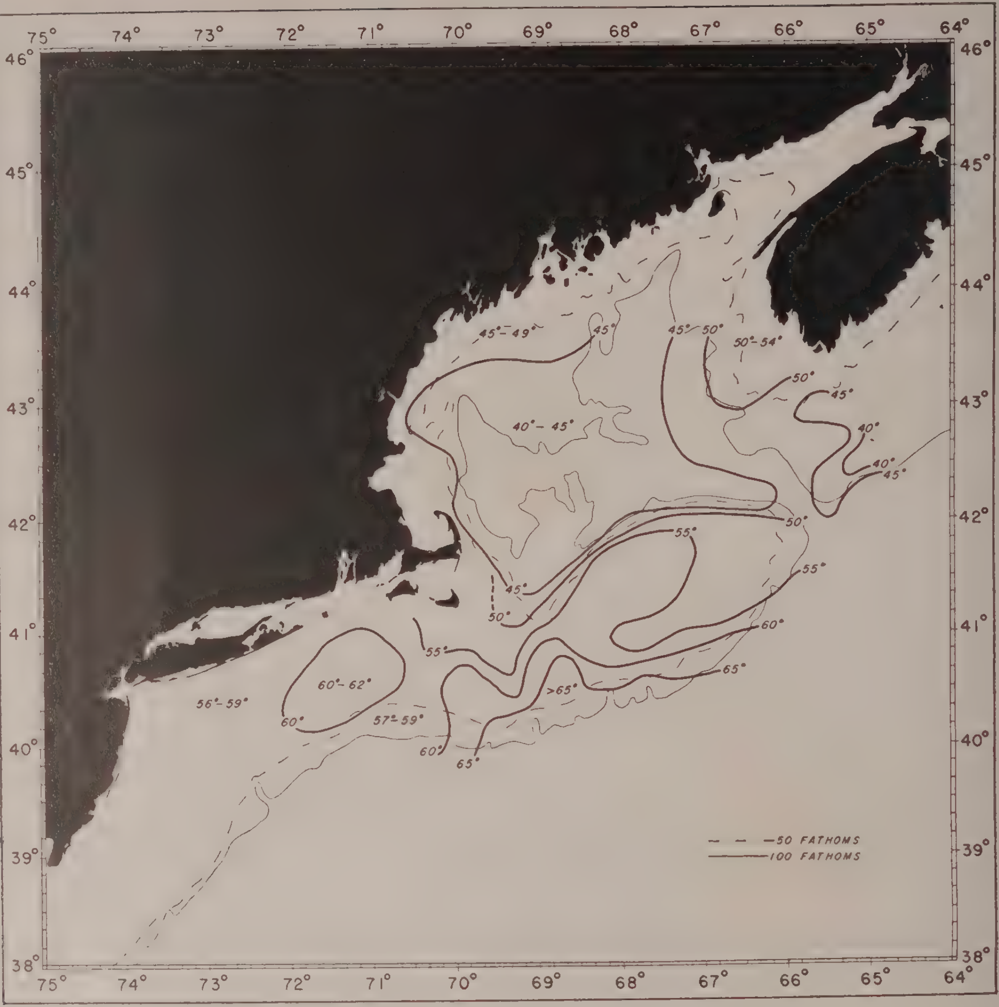

Fig. 4. Bottom water temperature in degrees Fahrenheit, November 1956.

mens occurring as deep as 124 fathoms. *P. propinquus* is a relatively deep water inhabitant and commonly occurred in waters between 90 and 180 fathoms in depth. One specimen of this species was found in 30 fathoms.

To summarize briefly, these catch records disclose that during November, *D. leptocerus* was most commonly found in shallow and moderately deep water. *P. borealis* and *P. montagui* were most abundant at moderate depths. *P. propinquus* was most common in relatively deep water. There were no pronounced diurnal differences in the catch for any of the 4 species.

Temperature Relationships

Pandalid shrimps in New England waters may be restricted in their geographic distribution by temperature barriers. The relationship between water temperature and occurrence of these shrimps, by species, may be examined from 2 aspects: (1) a comparison of geographic distribution with bottom water isotherms, and (2) a comparison of ranges in water temperature at specific localities where each species occurred.

Isotherms of bottom water, based on measurements taken at trawling stations and at 57 intermediate locations, are plotted in Figure 4. This figure discloses the presence of a sharp temperature gradient along the northern border of Georges Bank. The 45°F and 50°F isotherms are closely adjacent on this edge of the bank. A comparison of the geographic distribution of each species of shrimp (Fig. 2) with the temperature isotherms (Fig. 4) reveals several interesting facts. It may be observed that *Pandalus* was not taken south of this zone of pronounced temperature change. Possibly the 50°F isotherm acts as a barrier to the southward spread of *Pandalus.*

Water temperature apparently has little effect on the distribution of *Dichelopandalus* under the conditions existing at the time and places these collections were made. However, isotherms of bottom water suggest that temperature may influence the distribution of species of *Pandalus*, but this is brought out more clearly in the following discussion.

The range in water temperature in which each species

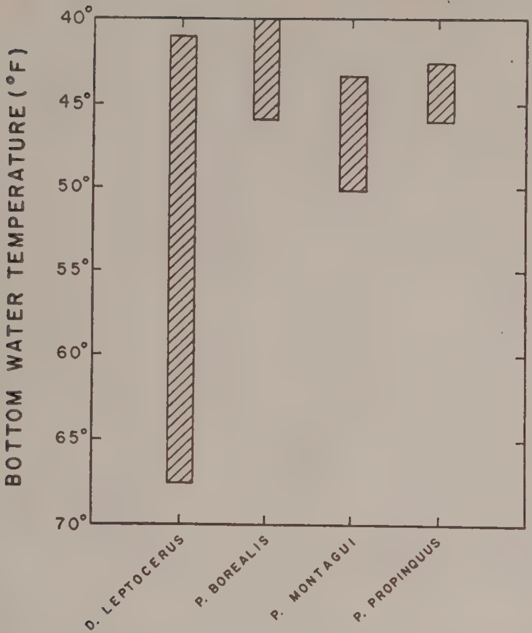

FIG. 5. Range in bottom water temperature (°F.) associated with each species of shrimp.

of shrimp was found is illustrated in Figure 5. This graph serves to emphasize 2 points. (1) It clearly reveals the wide temperature range, from 41° to 68°F, inhabited by *D. leptocerus*. (2) It illustrates the colder and relatively narrower range in temperature associated with all 3 species of *Pandalus;* all occur within a range of 40°-50°F. Comparatively small differences in temperature ranges among these 3 species are evident. *P. borealis* was taken in the coldest waters, 40°-46°F. *P. propinquus* was found in slightly warmer waters, 43°-46°F. *P. montagui* occurred in still warmer waters, 43°-50°F.

Bottom Sediment Relationships

It is an established fact that bottom sediments have a significant influence on the occurrence of many benthonic marine organisms. This dependency on sediment varies according to the animal's habits and requirements. Pandalids feed on living or dead plants or animals; therefore, the associations between species-occurrence and sediment-type may be either a direct or indirect relationship, or a combination of both. A distinct relationship between abundance of pandalid shrimp and the amount of organic matter in the sediment has been demonstrated by Hjort and Ruud (1938) and Bigelow and Schroeder (1939). Referring primarily to *P. borealis* in Gulf of Maine waters, Bigelow and Schroeder found these shrimp to be most abundant where the sediment organic content averaged 4.0%. In adjacent localities where the organic content averaged 3.0%, these shrimp were definitely less common.

New information on this subject is presented here, pertaining to pandalids in the vicinity of Georges Bank. Sediment samples from 223 localities on or near Georges Bank were analyzed for organic content.[1] The quantitative geographic distribution of sediment organic content based on these samples is illustrated in Figure 6. A comparison of pandalid distributions (Fig. 2) with the distribution of sediment organic content reveals 2 points of interest. First, it substantiates previous findings that *Pandalus borealis* is not common where sediment organic matter is low. Secondly, it indicates that *Dichelopandalus* is less restricted than *Pandalus* in this respect. *D. leptocerus* was usually more abundant where the sediment organic content was greater than 0.5%, but it was prevalent over a large area where the organic content was very low, 0.5 to less than 0.1%.

In regard to *P. montagui* and *P. propinquus*, the evidence is less conclusive. *P. montagui* was found to occur at a few localities where the sediment organic content was very low (less than 0.1%) and it was not taken where the organic content is known to be high (3 to 4%). *P. propinquus* was collected over diverse sediment types representing a wide range in sediment organic content. In some localities where this species was taken, the organic content was low, but it was most common where the organic content was at an intermediate or high level.

SUMMARY

The 4 species of Pandalidae common in New England offshore waters are: *Dichelopandalus leptocerus* (Smith), *Pandalus borealis* Kröyer, *Pandalus montagui* Leach, and *Pandalus propinquus* G. O. Sars.

Otter trawl catches of these shrimps in November 1956, in the area from Long Island northward to the central Gulf of Maine and eastward to Cape Sable, Nova Scotia, reveal some distinct relationships between species distribution and environmental factors.

Dichelopandalus leptocerus was ubiquitous over the entire study area and was taken in a wide range of water depths (20 to 190 fathoms) and a broad range in temperatures (41° to 68° F). It was common over sediments containing low, medium and high quantities of organic matter.

Pandalus borealis occurred in a limited portion of central and western Gulf of Maine. It was found only in waters of moderate (60 to 110 fathoms) depth, rather low temperatures (40° to 46°F), and over sediments high in organic content.

Pandalus montagui inhabited the periphery of the Gulf of Maine basin. This species was most common in moderate depths (40 to 70 fathoms), moderately low temperatures (43° to 50°F), and appeared to be associated with sediments relatively low in organic content.

Pandalus propinquus occupied the central Gulf of Maine basin. It was usually found in deep (90 to 180 fathoms), moderately cold (43° to 46°F) water, and was most common over sediments containing medium or high quantities of organic matter.

Diurnal periodicity of occurrence in the catch was not apparent for any of the 4 species.

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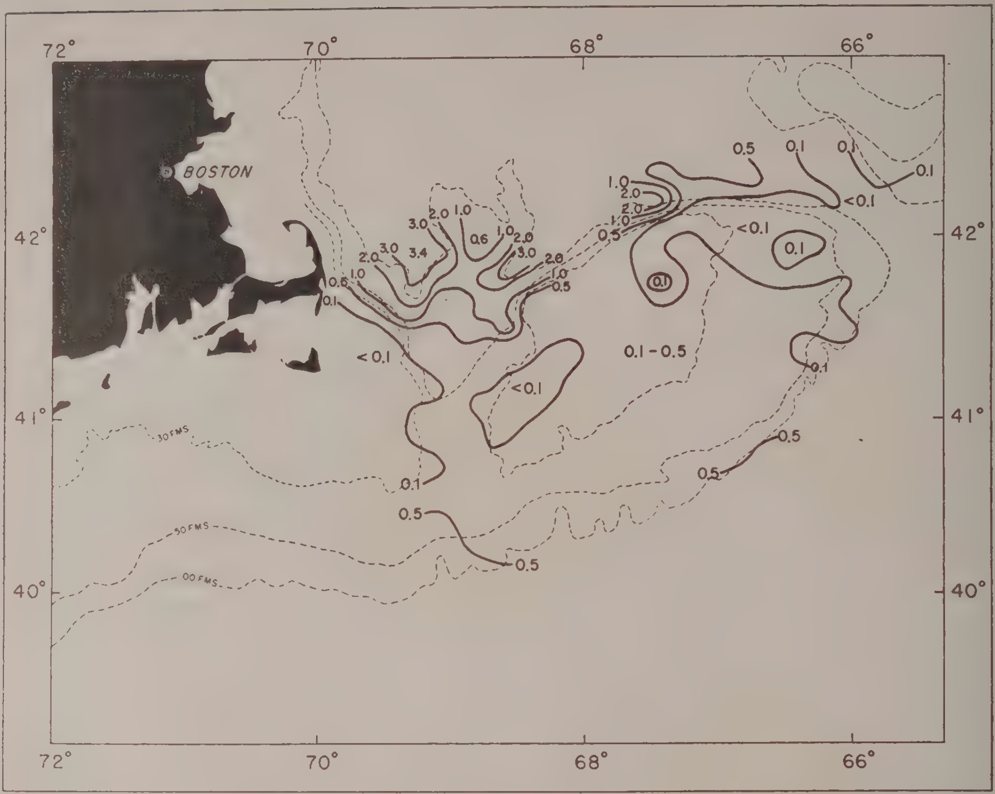

FIG. 6. Geographic distribution of organic matter in sediments on Georges Bank and vicinity. Values are given in percentage weight.

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#85

DANGEROUS MARINE ANIMALS. *By Bruce W. Halstead. Cornell Maritime Press, Cambridge, Maryland. 1959, 146 pp. 86 figs. $4.00.*

This little book is in part a semipopular version of a projected comprehensive treatise on toxic marine organisms. As such it will doubtless have much wider circulation than its parent work.

There is first a brief and interesting review of past information and misinformation going back to the Greeks and Romans. The following text is divided into three major sections: marine animals that bite; marine animals that sting; and marine animals that are poisonous to eat. The division, good in principle, is somewhat curious in practice. For instance, the bites of cephalopods, polychaetes, and snakes are listed under "stings", while the giant clam is considered a "biter". Moray eels are included as biters and also for no clear reason as stingers, since the author discounts any venomous apparatus. The general plan of each section lists harmful species or higher taxa, then gives methods for identification and a description of the particular harmful or toxic mechanism. Last is a paragraph or two on medical aspects and treatment, and practical hints on prevention. In discussing the medical aspects and treatment the author, a physician, is at his clearest and most authoritative.

Unfortunately, most of the treatments, except for surgical attention to bites from large fishes, are palliative at best. The basic plan seems to be removal of poisonous substances where possible, followed by nursing and rest. However, most of the accidents can be prevented, and the rules for prevention are sound and plentifully larded with common sense.

Illustrations of dangerous animals are abundant, well chosen, and remarkably well reproduced for offset printing. The overall effect of the illustrations is unfortunately marred since many are taken from other sources, and even the figures prepared especially for this volume vary from pencil sketches through ink drawings to airbrush paintings and photographs. Sometimes various techniques are combined in the same figure, with less than artistic results.

Nonetheless, this book should prove desirable for the marine fishery biologist's library and a good field handbook. Skindivers, collectors, and medical men, especially those who operate in tropical or semitropical seas, will find it most useful.

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